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# Fluctuations of Fish Stocks and The Consequences of the Fluctuations to Fishery and Its Management

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March 1982

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## LIST OF CONTENTS

	<u>Page</u>
Abstract .....	iii
1. Purpose and background of this report .....	1
2. Observed fluctuations of fish stocks .....	3
3. Plausible causes of fluctuations of fish stocks and numerical methods for their study .....	12
4. Periods and magnitudes of natural fluctuations of fish stocks in the eastern North Pacific as determined with ecosystem simulation .....	19
Effect of temperature anomalies .....	19
Effect of increasing the pollock catch .....	28
Effect of a reduction in marine mammal consumption .....	28
Fluctuations of total biomass .....	32
5. Rates of changes of biomasses and “stock recovery” rates .....	38
6. Implications of the fluctuations of stocks to fishery .....	43
7. Rational fisheries management of fluctuating stocks .....	45
8. Summary .....	49
9. References .....	52

## ABSTRACT

The fish stocks are known to fluctuate considerably in abundance without the effect of fishery as well as because of the variable fishing effort. The study of these fluctuations and their causes is one of the important tasks for fisheries scientists. It is imperative to know the causes, magnitudes, and periods of the “natural fluctuations” of stocks in order to evaluate the effects of fishing on the stocks and to propose management measures.

The short-term fluctuations of stocks (with periods of a few years), although recognizable in landings, are not fully reflected in the catch data mainly due to efficient fish search (detection) methods in use. The short-term fluctuations are, however, well documented in quantitative evaluation of annual stock sizes. There are also long-period fluctuations (decades and longer), especially in pelagic species. The main causes of the fluctuations of stocks are environmental anomalies, periodicities in recruitment caused by exceptional year class successes and/or failures, interspecies and intra-species interactions (the former being mainly manifested in interspecies predator-prey relations, the latter in cannibalism), and fishery.

The fluctuations of stocks in the Bering Sea and Gulf of Alaska (depicted in terms of changes of biomass of the species) have been studied with the Prognostic Bulk Biomass (PROBUB) ecosystem simulation model. The total finfish population fluctuates little from year to year. Longer lasting temperature anomalies have the greatest effect on total biomass fluctuations. However, individual (species) biomasses fluctuate considerably. The average period of these fluctuations varies from species to species and is between

three and eight years. Long-period changes (in the order of decades) are superimposed on these fluctuations. The magnitudes of fluctuations also vary from species to species and are between 35% and 80% of equilibrium biomasses. A rough average magnitude of fluctuations of all biomasses is 70% of individual equilibrium biomass. Density dependent predation' regulates the magnitudes of these fluctuations to a considerable extent.

Rates of annual changes (which can also be considered as meaning "recovery rates" vary from about 10% of mean annual biomass per year (flatfishes) to about 40% of annual biomass per year (short-lived and pelagic species). These rates of changes refer to constant recruitment, where spawning biomass is not a limiting factor.

Temperature anomalies affect the fluctuations of the finfish biomasses to a considerable extent. These effects vary,- however, from species to species, being smallest in flatfishes and largest in pelagic species, and from region to region, being largest in northern regions. Predator-prey relations interact with the effects of temperature anomalies.

Changes in fishery and in predation by mammals influence the fluctuations to a varying extent. Intensive fishery on some species decreases the biomasses and suppresses the magnitudes of fluctuations. A fishery which can switch the emphasis of target species, can utilize the fluctuations by increasing the catches of abundant species (at the apex of fluctuations). Rational fisheries management aimed at full utilization of the renewable resource must thus consider the "natural fluctuations" of biomasses and should be flexible from year to year rather than attempting to achieve a maximum sustainable yield (MSY).

## 1. PURPOSE AND BACKGROUND OF THIS REPORT

One of the main tasks of fisheries scientists is to determine the magnitudes of fishery resources (stocks), factors affecting their changes, and their response to fishing. This information is used by management to decide how renewable resources are to be utilized in a given socio-economic setting. A requirement exists to utilize a renewable food resource fully, without harming the productive capacity of the marine ecosystem.

A characteristic of the marine fisheries ecosystem is that it is subject to never ending fluctuations. It has been pointed out by many (e.g., Smith 1978) that fish populations are observed to undergo sustained increases and decreases for several decades without a commercial fishery. Smith (1978) has also discussed the causes and the space and time scales (especially the longer ones) of these fluctuations. The data obtained by systematic fisheries surveys of various kinds are the means of ascertaining the changes of fish stocks and determining possible causes. Systematic sampling by fisheries surveys is expensive and therefore cannot cover all areas and stocks in desired details. It is necessary to supplement these surveys with other sources of information.

In the last decade the International Council for the Exploration of the Sea (ICES) has held several symposia on the changes of fish stocks. Numerous reports presented at these symposia demonstrate that large changes occur in marine fish stocks which cannot be explained, neither as a result of fishing alone nor as a result of the effect of a single environmental factor. Partly as a result of this understanding, the single-species population dynamics approach as the main tool for deciding fisheries management options finds lesser use. Instead large, complex ecosystem simulation models have been

programmed, which are being increasingly used both for the study of the processes in the ecosystem which cause its fluctuations, as well as for computation of the possible response of the ecosystem to proposed management actions. These ecosystem simulations do not replace fisheries surveys, but compliment them.

The purposes of this study and report are:

- 1) To present some of the empirical evidences of the fluctuations of fish stocks.
- 2) To review the plausible causes of these fluctuations.
- 3) To simulate these fluctuations with Prognostic Bulk Biomass (PROBUB) model and to determine the mean periods and plausible magnitudes of these, fluctuations.
- 4) Study species interactions in these fluctuations.
- 5) Determine the effects of environmental anomalies and fishery on the fluctuations of stocks.
- 6) Determine the rate of changes of biomasses (“recovery rates”).
- 7) Investigate the implications and consequences of “natural fluctuations” of stocks on rational fisheries management.

## 2. OBSERVED FLUCTUATIONS OF FISH STOCKS

It is not possible to observe any change of stock in smaller than annual intervals, as monthly and/or seasonal sampling is affected by seasonal migrations and availability of the species. Year-to-year variations of stocks can be observed by examining either catches (landings), biomass levels (computed, using cohort analyses), or year class strengths. All three methods have shortcomings. Landings are affected by fishing intensity, market conditions, search methods, and fish availability. Year class strengths can vary considerably from year to year; however, these variations are “buffered” by the presence of many year classes in the exploitable part of the population. Jones and Hislop (1978) pointed out that, although North Sea haddock year class strengths varied 3 orders of magnitude, its biomass carried only one order of magnitude. The catch per unit effort varied only maximum half order of magnitude. Despite the shortcomings of the methods available for examining stock fluctuations, the data show undoubted fluctuations of the stocks (Figures 1 to 9). Figure 1 shows the total catch of Norwegian spring-spawning herring from 1925 to 1973. This fishery is very dependent on search methods and on improvement of purse seining and midwater trawling gear and methods; thus the catches do not necessarily reflect the stock size. However, the period in the mid-fifties (about 5 years) reflects the higher abundance of herring during this period. The collapse of fishery after 1967 is due to “recruitment failure” caused by several factors.

Figure 2 shows the herring catches in the International Commission for the North Atlantic Fisheries (ICNAF) area (NW Atlantic), indicating a period (about 7 years) of higher catches in the late sixties. However, the catches vary from subarea to subarea, reflecting, partly the spatial

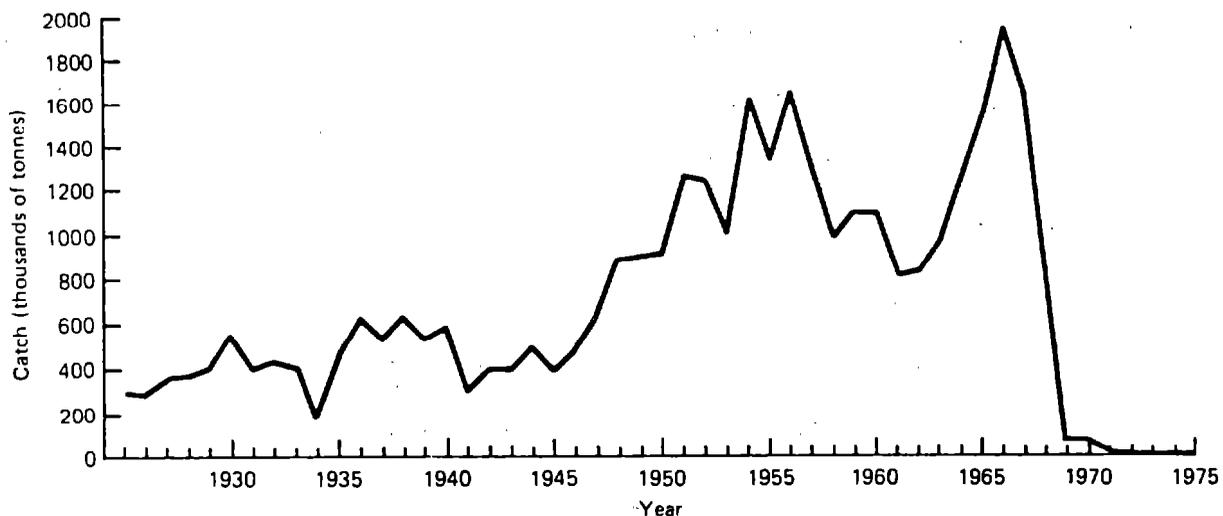


Figure 1. --Catches of Norwegian spring-spawning herring (after Schumacher 1980).

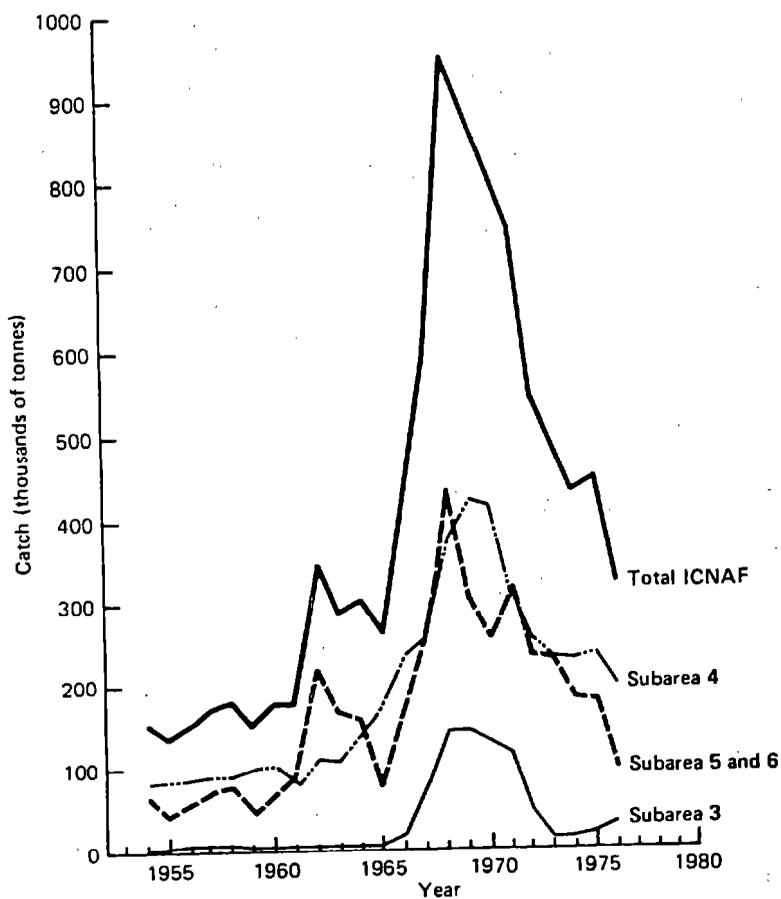


Figure 2.--Herring catches in the ICNAF area (after Schumacher 1980).

variability in availability. A 5 to 7 year fluctuation of catch could be recognized in most of the ICNAF subareas. These fluctuations might, however, be caused by factors other than stock size. An example of the possibility that variations in catches might not reflect variations in stocks is given in Figure 3. Although the USSR catches of Pacific herring from the Bering Sea might indicate a ca 6-year fluctuation, these fluctuations do not occur in Japanese catches from the same sea. Thus, the USSR catches might have varied for reasons other than the availability of herring (e.g., redirection of fleet effort).

Figure 4 shows long-term fluctuations of California sardine catches and the shift of the sardine population southward in recent times. It is known from the observations on distribution of many fish stocks that a decreasing stock shrinks in the area of its distribution, the fringe stocklets disappearing first.

The landings of the fish given in Figures 1 to 4 were largely determined by the change of fleet capacities and by the improvement of search and catch methods. Therefore, the year-to-year fluctuations of the local stocklets and local availability of pelagic fish would not appear clearly in these data. However, local fisheries, where the technology changes but slowly, indicate much more clearly the short-period (a few years) fluctuations, such as shown in Figure 5.

A fishery on "small herring" (smasild, 0 and 1 group fish) and "fat herring" (1 to 4 group). is conducted in the fjords and at the coast of northern Norway. Figure 5 shows that considerable fluctuations in the availability of this herring have occurred between 1930 and 1964. (After

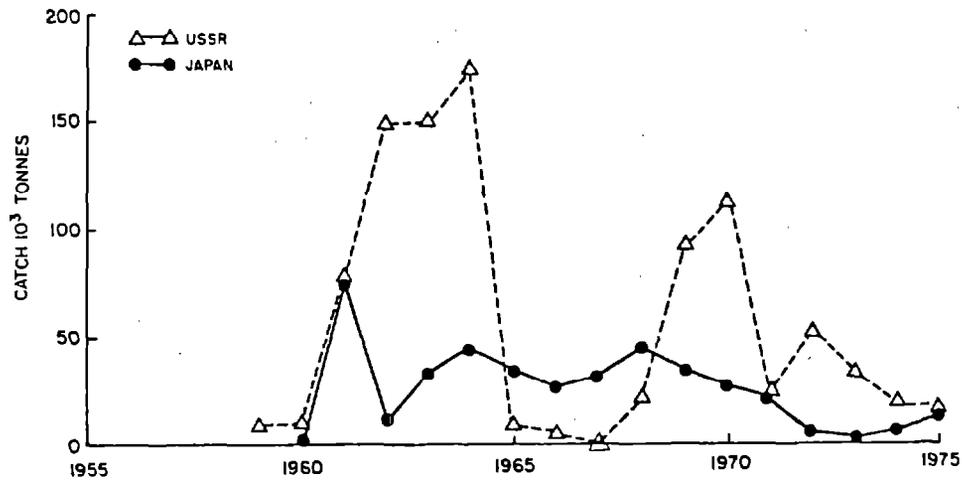


Figure 3. - - Japanese and Russian catches of herring from the Bering Sea.

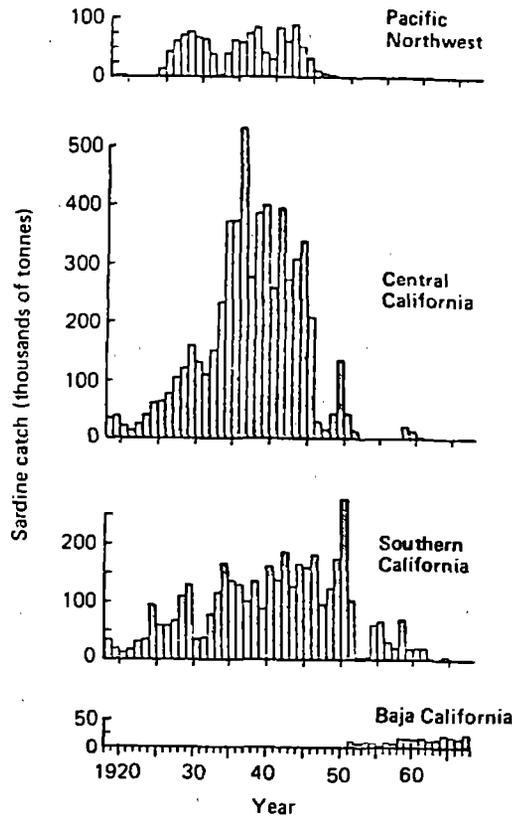


Figure 4.--Time series of seasonal catch of Pacific sardine by region (from Smith, 1978).

1964 a ring-net technique was used in the small herring fishery). Data presented in Figure 5 indicate a 4 to 8 year periodicity of catches.

Catches of local fisheries of Pacific herring along the Canadian coast are shown in Figure 6. These data reveal considerable fluctuations with varying periods. The North Sea stock of herring also shows irregular periodic fluctuations (Figure 7) ; approximately a 4 to 5 year periodicity seems to predominate (Burd 1978). De Veen (1978) has shown a roughly 5-year cycle in the landings of North Sea sole (Figure 8). This figure also shows another general characteristic of the fluctuations of stocks--the higher the stock, the greater is the magnitude of fluctuation.

The relative recruitment (in numbers, as computed with cohort analysis) to seven fish stocks is shown in Figure 9 (Garrod from Cushing 1981). Rather profound fluctuations of recruitment in all fishes is apparent in this figure ; in some species the fluctuation exceeds two orders of magnitude. As there are many factors affecting these fluctuations, a strict (regular, harmonic) periodicity cannot be expected. The length (here called period) of these fluctuations varies from species to species, from a few years to less than ten years. Year class strength can vary in some species up to 3 orders of magnitude (e.g., haddock, see Holden 1978, Table 3a). The year class strength fluctuation is smallest in flatfishes (maximum ca 1 order of magnitude, Holden 1978). The fluctuations of biomasses are, however, considerably smaller than the fluctuations in numerical strengths of year classes because the biomass is buffered by the presence of several year classes.

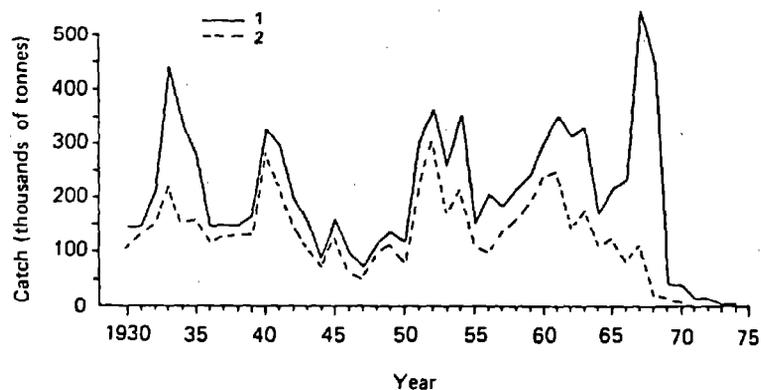


Figure 5. --Catch of young and adolescent Norwegian herring in 1930-1974 (from Dragesund et al., 1980); 1 - total catch; 2 - small herring.

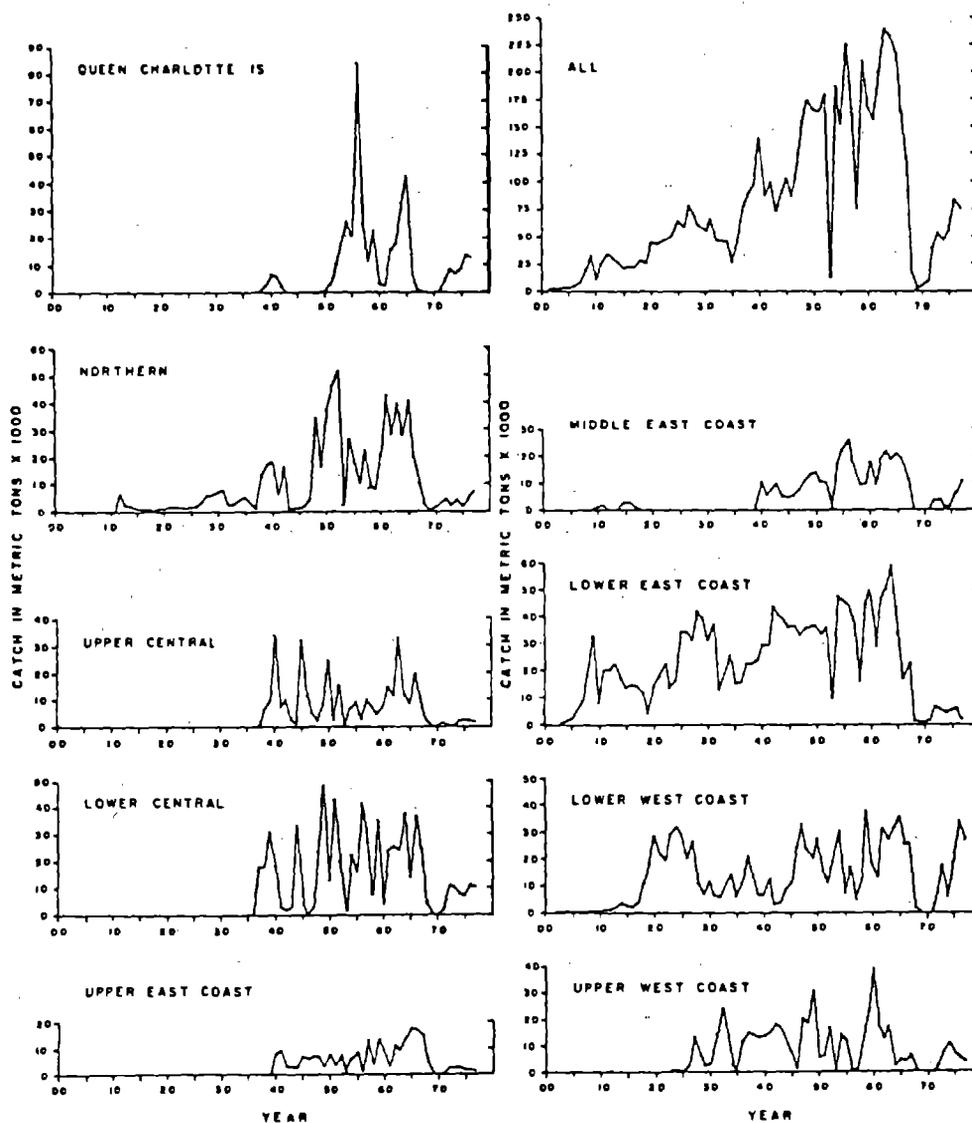


Figure 6. --Annual catch from British Columbia herring populations, 1901-1977 (after Hourston 1980).

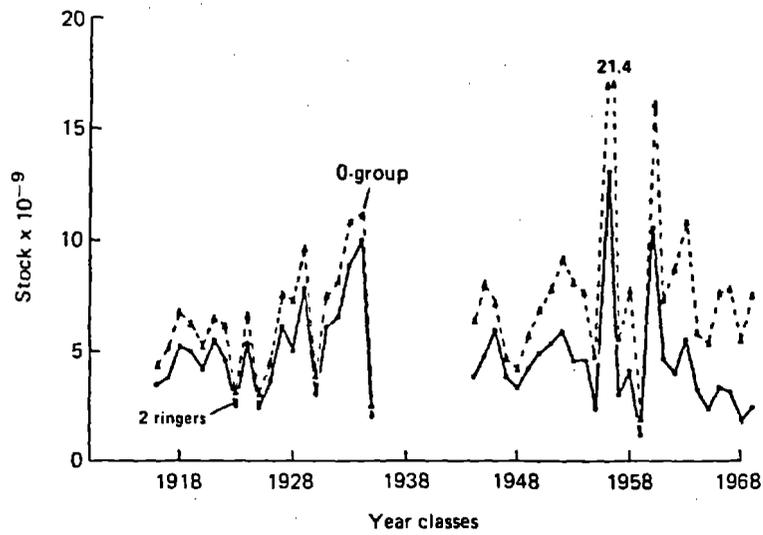


Figure 7.--Estimates of stock of two-ringers and O-group herring in the North Sea (from Burd, 1978).

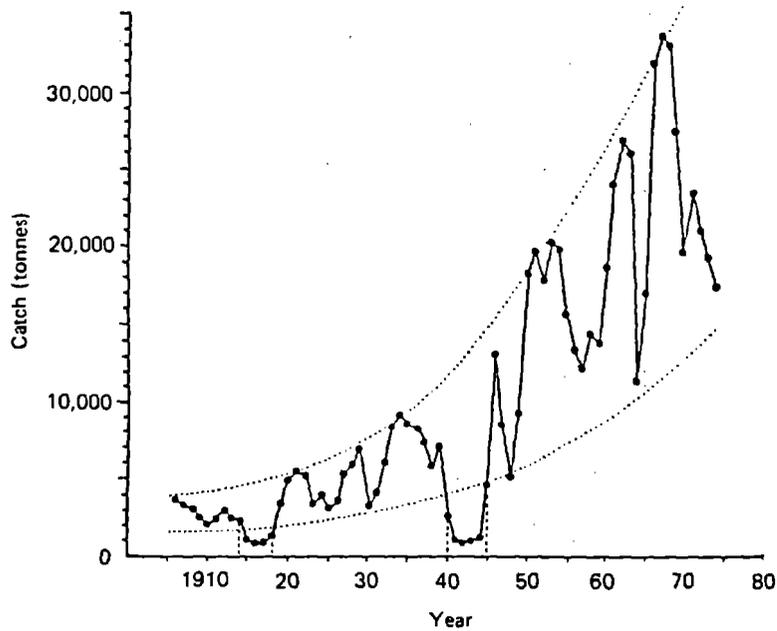


Figure 8.--Total international landings of North Sea sole (after De Veen, 1978).

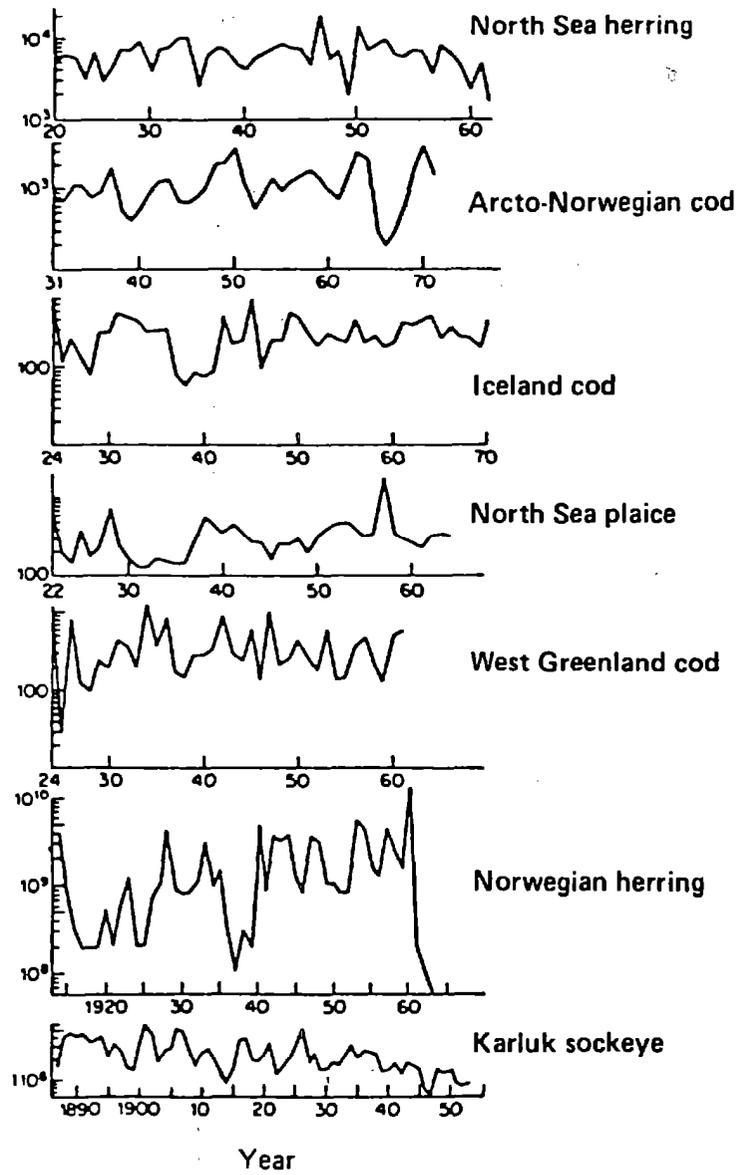


Figure 9.--Recruitment to a number of fish stocks estimated for decades by cohort analysis (pers . comm. of Garrod from Cushing 1981).

Table 1. --Major factors causing fluctuations in marine fish ecosystem.

<u>Factors</u>	<u>Main effects</u>
<u>External factors</u>	
Temperature anomalies	Changing metabolic rate (affecting growth and food uptake)
Fishing	Changing abundance of older biomass, thus affecting predation, cannibalism, and recruitment
<u>Internal factors</u>	
Predation (including cannibalism)	Affecting recruitment; main mechanism in interspecies interaction in predator-prey system.
Competition	Interspecies interaction in predator-prey system; starvation (affecting growth)
Migrations	Changing predator-prey system by changing predator-prey overlap (local density)

### 3. PLAUSIBLE CAUSES OF FLUCTUATIONS OF FISH STOCKS AND NUMERICAL METHODS FOR THEIR STUDY.

Conventional, single-species fish population dynamics has considered the effects of fishery as the main cause of changes in fish populations. Another popular assumed cause has been the recruitment variation in larval stage. The multitude of other causes has received relatively little quantitative attention.

The marine fisheries ecosystem is not stable and fluctuations within it occur even without the effects of fishery. The major factors affecting the fluctuations are listed in Tables 1 and 2. Any one of these factors can act independently of others and have different space and time scales. Thus, biomass fluctuations can be quite complex and irregular. Some regularity is, however, inherent in some internal processes. An example of periodic variations inherent in the ecosystem has been described by Sahrhage and Wagner (1978), who pointed out a three-year periodicity in the biomass of haddock in the North Sea which was initiated with the birth (and survival) of a good year class (Figure 10). This periodicity was later, however, disturbed and interrupted by other causes.

One of the main factors causing biomass fluctuations is the space and time varying predation on larvae and juveniles. This predation provides also the main mechanism of quantitative interspecies interaction. Predation is a density dependent process (depending on the densities of both predator and prey). Thus, it also limits the fluctuations at the extremes.

Table Z.--Consequences of changes in biomass, stabilization mechanisms and limiting factors.

<u>Cause for biomass change</u>	<u>Consequences and stabilizing effects</u>	<u>Limiting factors</u>
Increase of fishery	Decrease of adult biomass (might lead to decreased recruitment) Decrease of spawning stress and natural mortality (stabilization) Relative increase of prefishery juvenile biomass, thus increase of growth coefficient (stabilization) Decrease of cannibalistic predation (stabilization)	Decreased availability to fishery Decreased recruitment (recruitment overfishing)
Increase of growth rate (temperature anomaly effects)	Increase of biomass Increase of predation (higher food requirements) (stabilization)	Availability of food Biological limit to growth
Increase of predation (incl. environmental effects affecting predator-prey relations)	Decrease of recruitment to adult biomass Decrease of biomass growth coefficient (aging of population) (destabilization) Increase of individual growth is possible if food was limiting growth (stabilization)	Decreasing food density (availability)
Increase of recruitment, caused by:		
a) decreased predation, resulting in increased larval survival (also environmental effects possible)	Increase of biomass Increase of biomass growth coefficient (rejuvenation) Decrease of individual growth is possible (food availability) (stabilization)	Increasing prey density Increasing food requirement
b) increased spawner biomass	Increased spawning stress mortality (stabilization) Increased juveniles (Increased relative predation) (stabilization) Decreased food availability (stabilization)	Increased predation on juveniles (higher prey density; increased cannibalism)

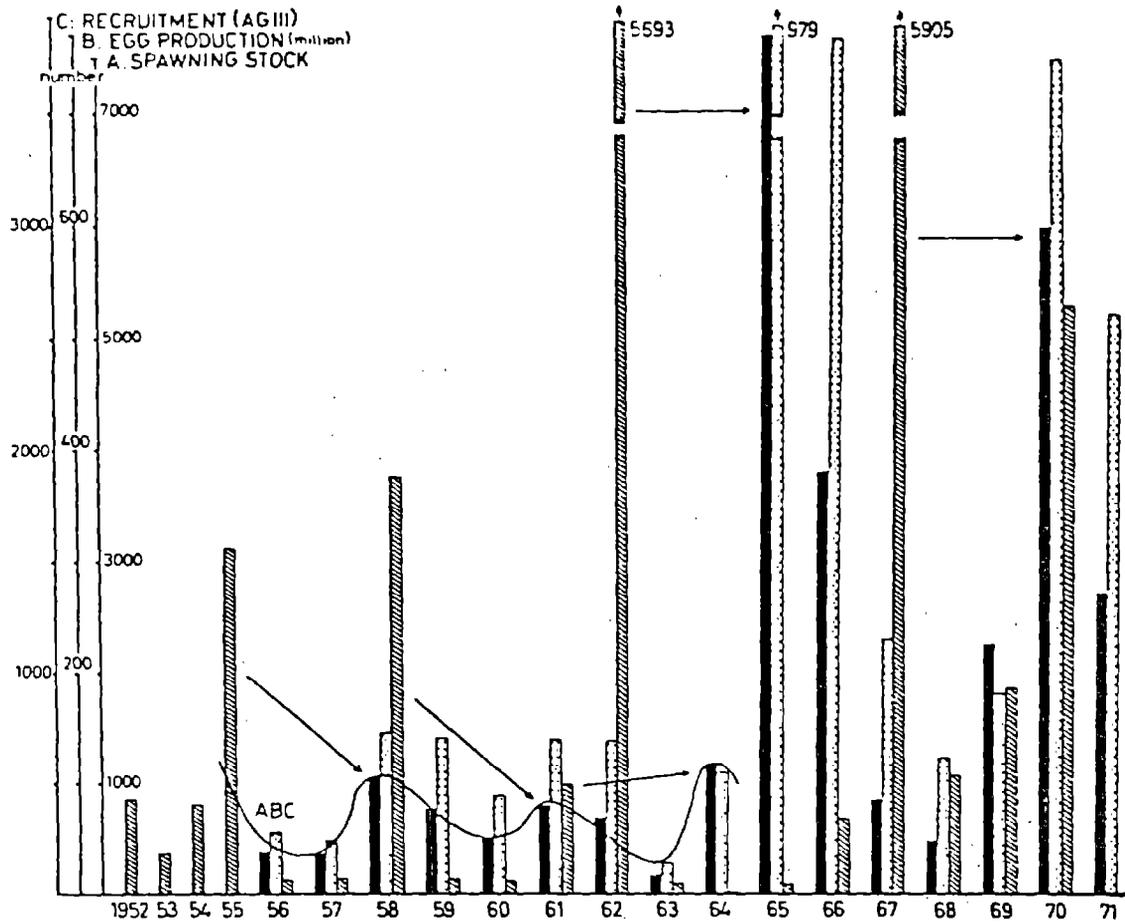


Figure 10.--Spawning stock size, egg production and resulting recruitment (measured as age-group III) of haddock from German survey data given in Table 35 (black columns) : Spawning stock; B (dotted columns) : Egg production; C [hatched columns) : Recruitment (from Sahrhage and Wagner 1978).

The annual food intake by fish is on the average about 3 times its annual mean biomass (standing stock). Thus, if the biomass changes, its total food intake will change correspondingly. Consequently the predation pressure upon prey species will change. Daan (1978) has shown that the biomass of cod in the North Sea has varied between 130 and 450 thousand tonnes between 1920 and 1973. The corresponding food intake by cod has varied between 400 and 1200 thousand tonnes annually. The variations of food intake is distributed between prey species in a complex manner, depending on their availability (density) and suitability.

Trophodynamic interactions are difficult to investigate empirically. However, holistic ecosystem simulations shed light on the possible nature of interactions. An example of trophodynamic interactions computed with an ecosystem model is given in Figure 11. This figure presents the fluctuations of cod biomass in two different regions in NE Pacific, as computed with PROBUB, and gives the corresponding fluctuations of the percentage of this biomass consumed by other species and groups of species. As seen from this figure, the fluctuations of biomasses and predation vary from one region to another. More importantly, however, this figure indicates that predation (consumption) can initiate fluctuations (i.e. increase of consumption precedes the decline of biomass) and can also act as “density dependent stabilizing mechanism” (i.e., decrease of consumption (fractional predation) precedes biomass increase --i.e., makes the latter possible).

The fluctuations of biomasses and their causes were studied with PROBUB, a holistic ecosystem simulation model (Laevastu and Larkins 1981). This model is rather elaborate and all-inclusive, as is needed for the understanding of the complexities in the ecosystem. This model reflects the Pythagorean dictum that all is numbers.

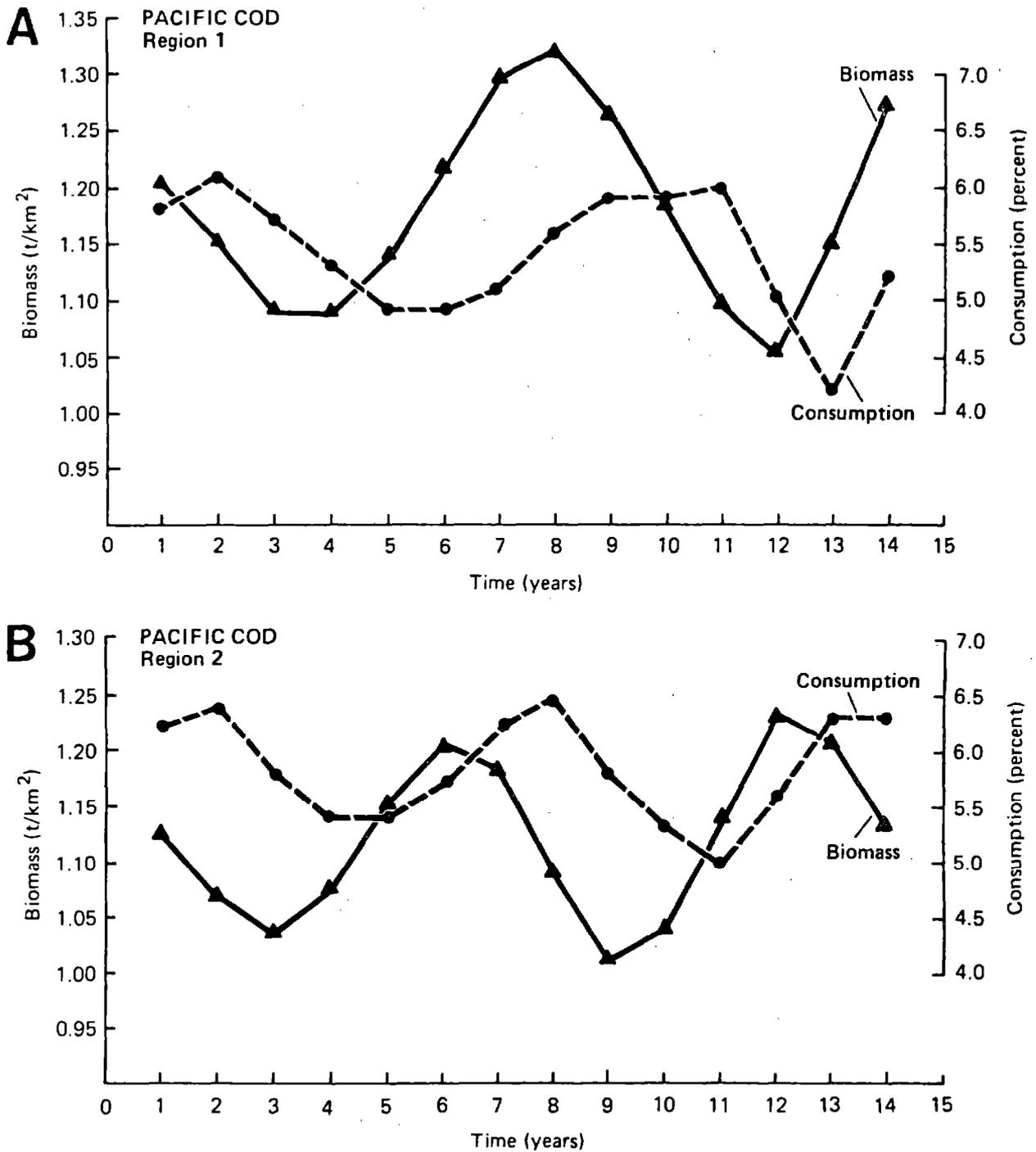


Figure II.--Fluctuations of biomasses of Pacific cod and percent of this biomass consumed by predators. A-Region 1; B-Region 6 (for Regions see Figure 13). Computed with PROBUB model.

Simplified basic components of biomass dynamics in this model are given in Figure 12. The model uses subregions which are assumed to be internally homogeneous (Figure 13). Although migration between the subregions was allowed when the model was used to determine equilibrium biomasses (see Laevastu and Larkins 1981), it was not allowed in studies reported here. The model includes all biota and essential environmental factors. Species interactions are brought about by predation as well as by competition for food. Feeding, although species-specific, is predator-prey size and availability (density) dependent. Larval recruitment is proportional to the spawning biomass present. Larval recruitment influences the recruitment to exploitable stock to a limited extent; the main influence on this recruitment is exercised by predation. In essence, the simulation model is based on described and observed quantitative facts and deduces new numerical results as a consequence of interactions of many processes.

$$B_{t+1} = B_t (2 - e^G) e^{-(F+M)} - C_t$$

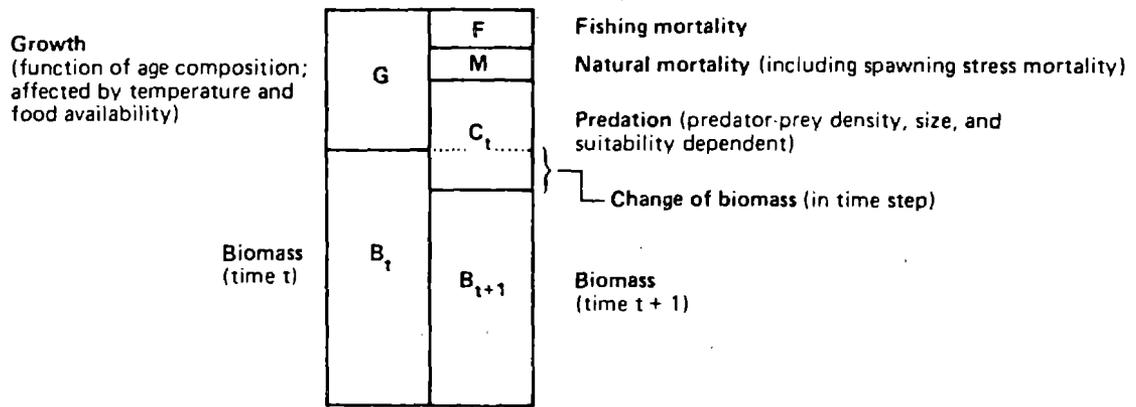


Figure 12. --Basic principles-of biomass dynamics in PROBUB ecosystem simulation.

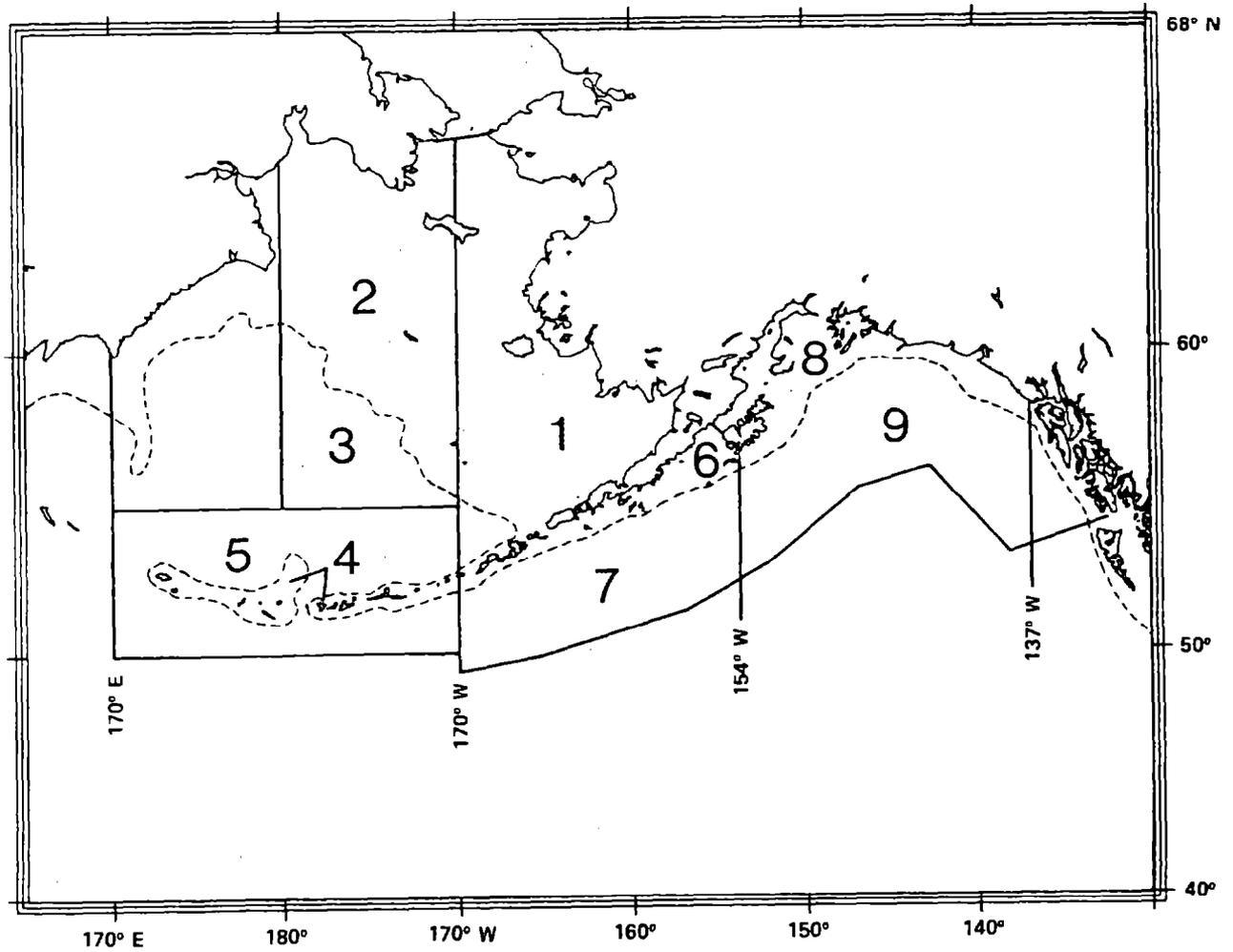


Figure 13.--Regions used in Bering Sea and Gulf of Alaska PROBUB.

#### 4. PERIODS AND MAGNITUDES OF NATURAL FLUCTUATIONS OF FISH STOCKS IN THE EASTERN NORTH PACIFIC AS DETERMINED WITH ECOSYSTEM SIMULATION

To examine fluctuations of fish stocks, it was necessary to establish a baseline for comparison purposes. This was done first by running the PROBUB model to equilibrium (Laevastu and Larkins 1981). Equilibrium was defined as that state where the biomass of the species and ecological groups in one January did not differ from the computed biomasses of the next January more than 2%. After reaching the above "equilibrium", the model was run for an additional 12 years. The resulting annual biomass fluctuations were considered the baseline. These results are shown on Figures 14 to 37 as the "normal" (or control) run. Several additional computer runs were made where water temperature anomalies, changing fishery, and changing predation by mammals were introduced (discussed later).

The computed "natural fluctuations" of the species biomasses in control run were found to have predominantly a 5 year period (varying from 4 to 7, depending on species). The magnitudes of the fluctuations for some species varied from one region to another. Further, they varied considerably from species to species. Flatfishes (Figure 20) had the least and benthos (Figure 26) the most.

##### Effect of temperature anomalies

In the first experiment negative temperature anomalies were introduced in all regions (-1.5°C in year 1, -2.5°C in year 2, and -1.5°C in year 3). The prescribed magnitudes of the anomalies compare favorably with available records (McLain and Favorite 1976). The temperature anomalies affect the growth rates in the model. The biomasses of selected species and regions, resulting from this experiment are shown with dashed lines in Figures 14 to 25.

General conclusions of the effects of the temperature anomaly on the fluctuations of biomasses, as depicted on Figures 14 to 25, are as follows:

a) The temperature anomaly effect on biomasses is larger in northern regions than in southern regions (Figure 14 versus 15; 17 versus 18) .

b) The temperature anomalies modify the apparent “periodicity” of biomass fluctuations (e.g., Figures 14 to 18). As the occurrence of temperature anomalies is not cyclic, it can partly explain why regular periodicities are not observed in fluctuations of stocks (Chapter 2).

c), The magnitudes of natural fluctuations of biomasses can be magnified by the anomaly effects (e.g., Figures 14, 16, 17).

d) The effects of anomalies vary from species to species; the effect was especially pronounced for cod (Figure 17).

e) The negative temperature anomaly can have a positive effect on predominantly prey species such as herring by decreasing the predation through suppression of the predator biomasses (Figure 19).

f) The effects of temperature anomalies on flatfishes are minimal (Figure 20).

g) The temperature anomaly effects on noncommercial (prey) species also varies from region to region (Figures 21 and 22) and the effects can also act as biomass stabilizers (Figure 22).

h) Crabs (Figures 23 and 24) and shrimps (Figure 25) show larger, anomaly effected fluctuations in northern regions (Figures 23 and 25) than in southern regions (Figure 24).

i) The biomasses of benthic epifauna and infauna fluctuate in opposite phase (Figure 26).

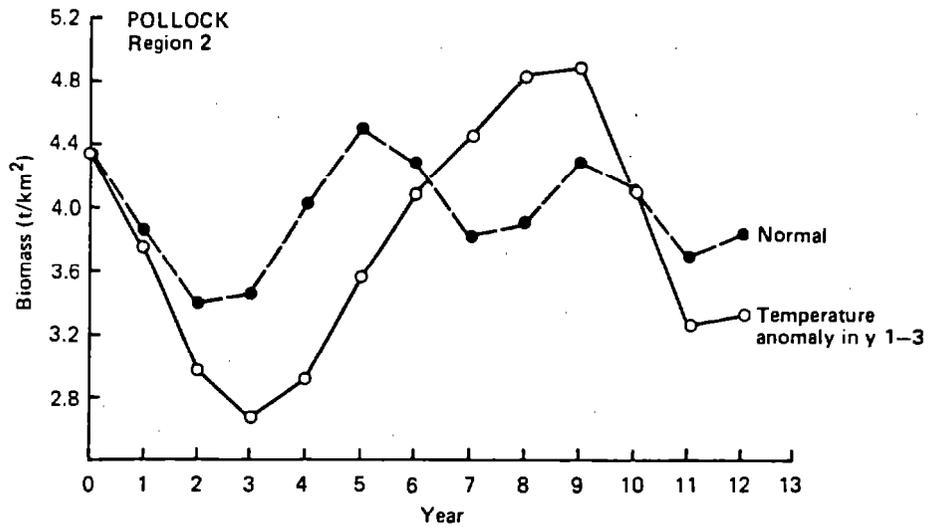


Figure 1b.-- Changes of pollock biomass (in t/km<sup>2</sup>) with time in Region 2 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

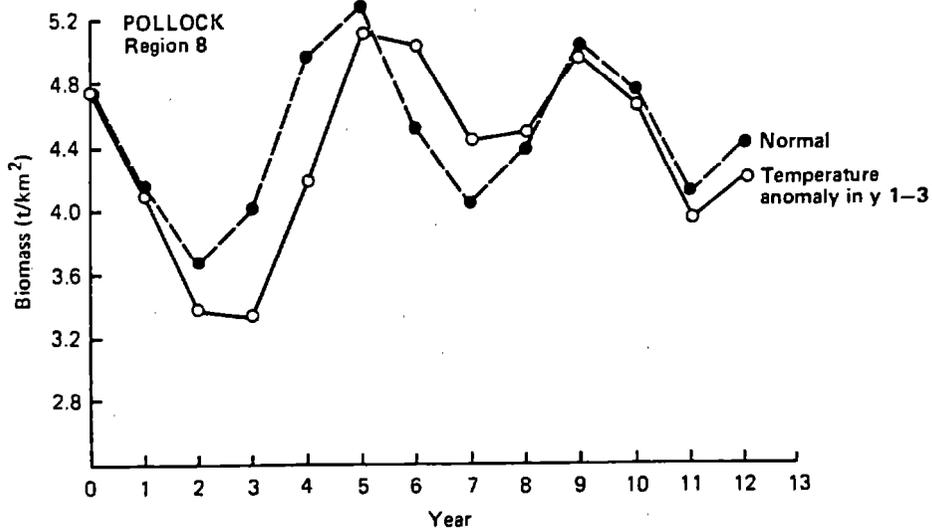


Figure 15.--Changes of pollock biomass (in t/km<sup>2</sup>) with time in Region 8 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

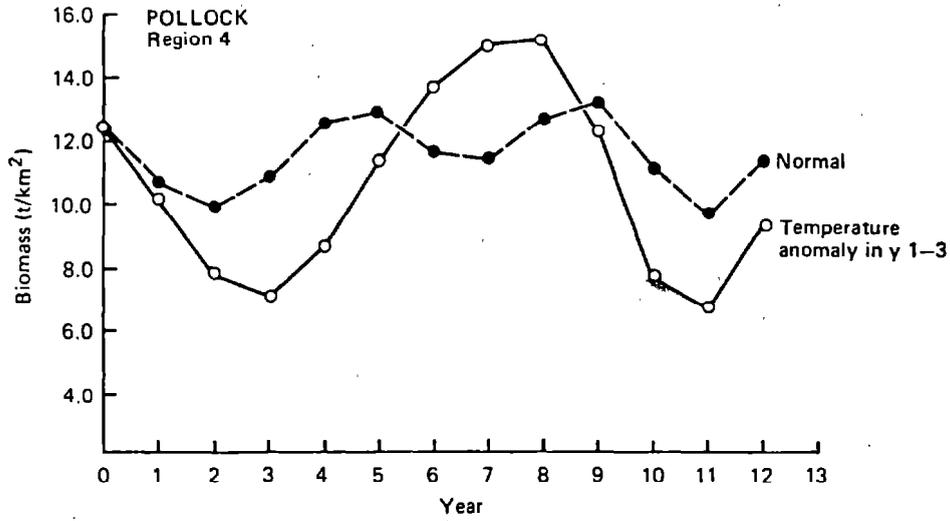


Figure 16.--Changes of pollock biomass (in t/km<sup>2</sup>) with time in Region 4 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

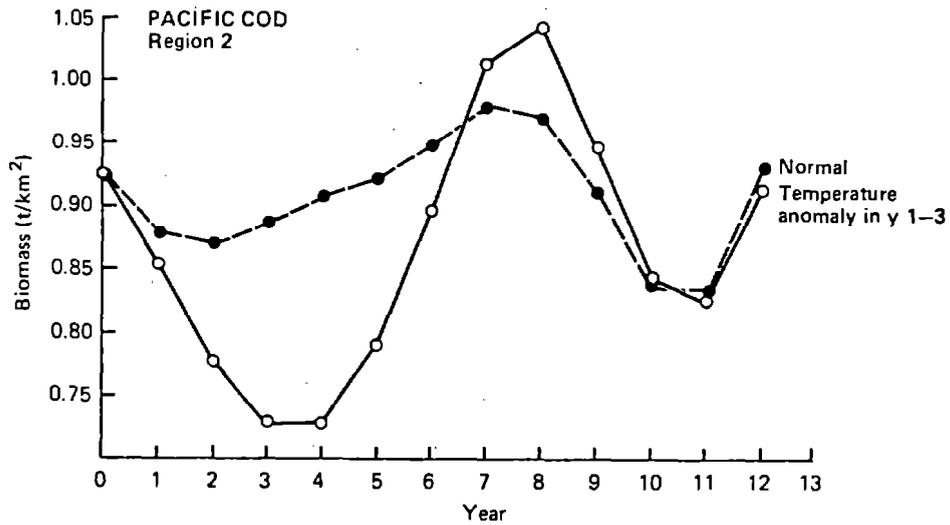


Figure 17.--Changes of Pacific cod biomass (in t/km<sup>2</sup>) with time in Region 2 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

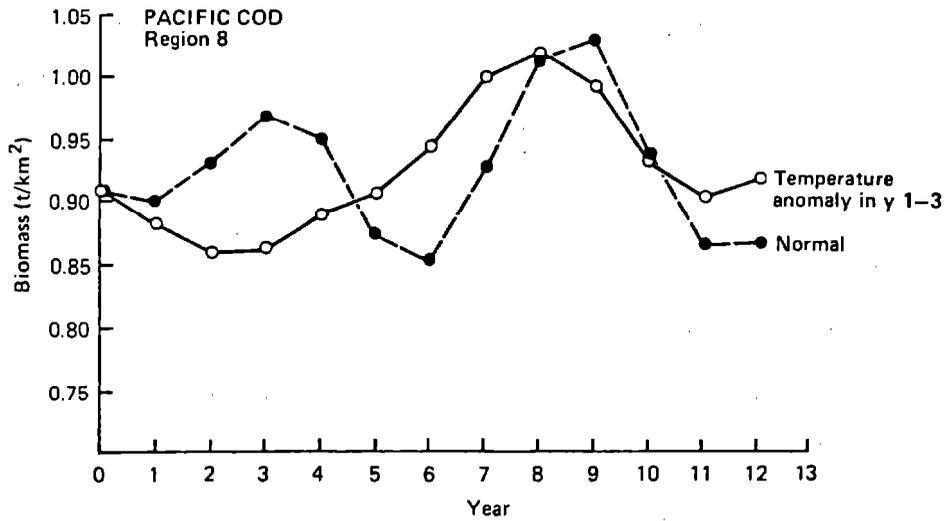


Figure 18. --Changes of Pacific cod biomass (in t/km<sup>2</sup>) with time in Region 8 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

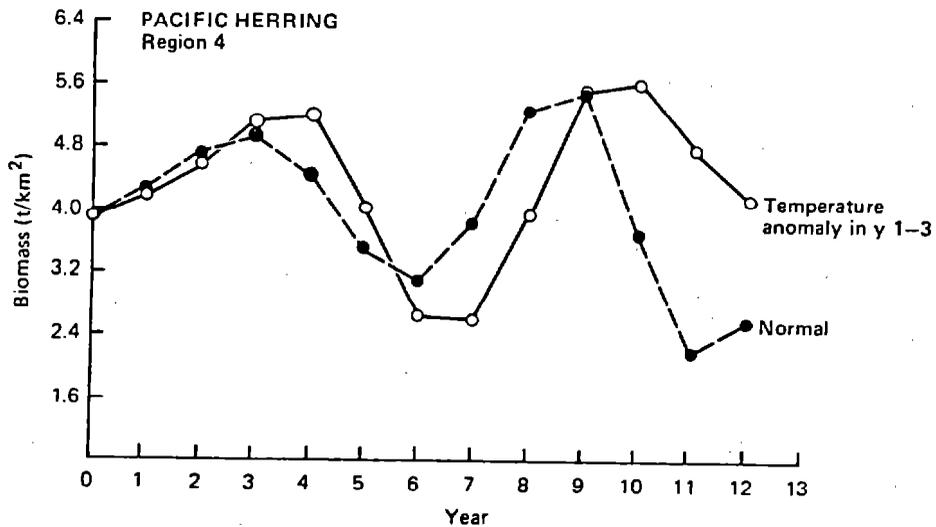


Figure 19. --Changes of Pacific herring biomass (in t/km<sup>2</sup>) with time in Region 4 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

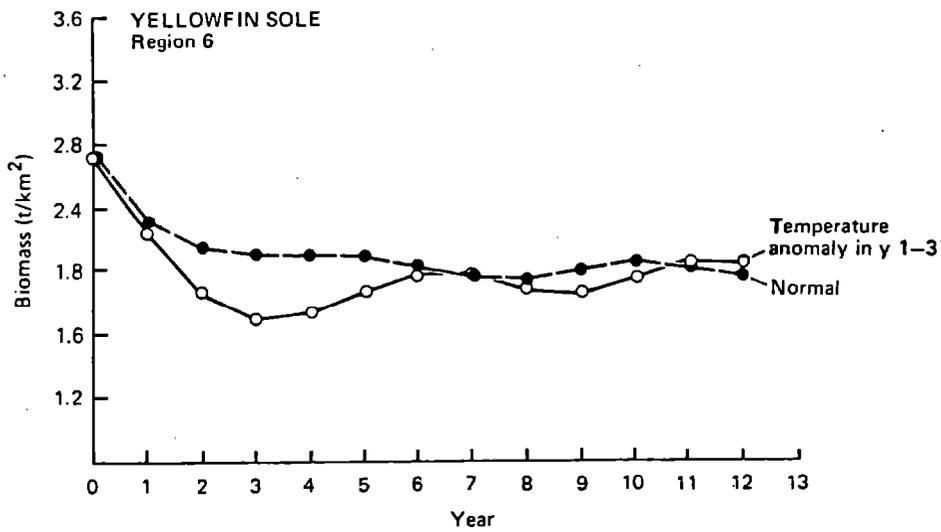


Figure 20. --Changes of yellowfin sole biomass (in t/km<sup>2</sup>) with time-in Region 6 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

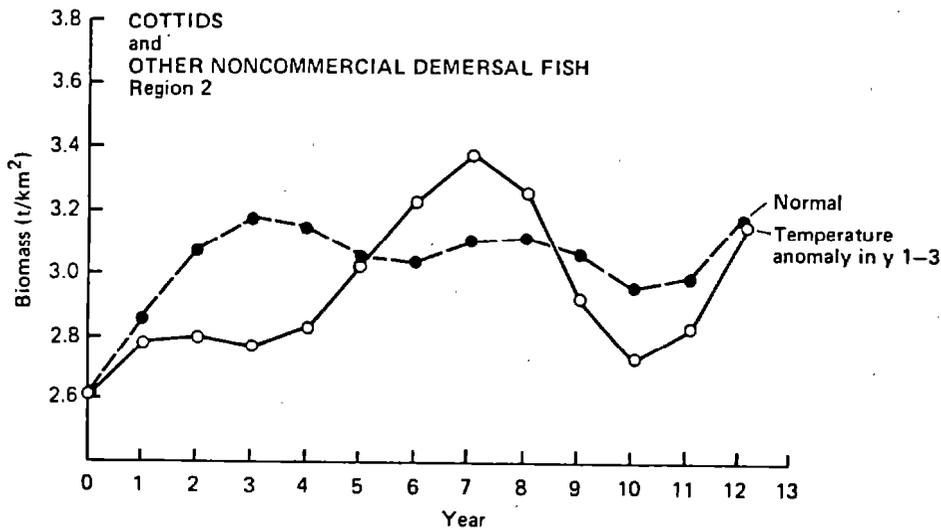


Figure 21. --Changes of cottids and other noncommercial demersal fish biomass (in t/km<sup>2</sup>) with time in Region 2 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5 ; -2.5 ; -1.5°C, respectively).

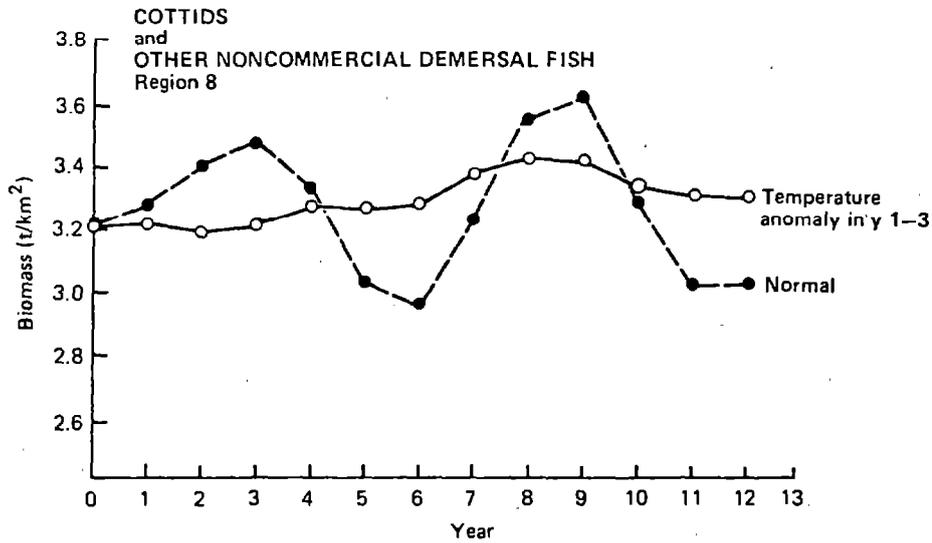


Figure 22.--Changes of cottids and other noncommercial demersal fish biomass (in t/km<sup>2</sup>) with time in Region 8 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

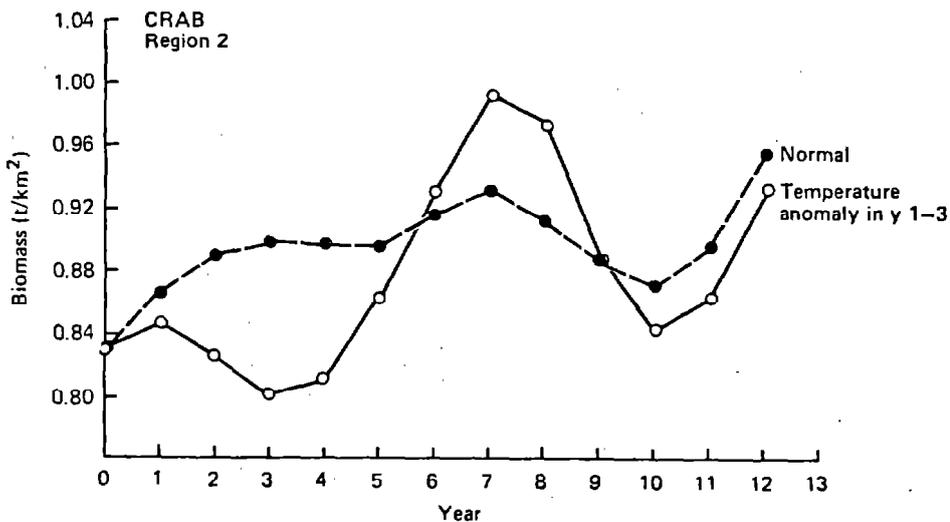


Figure 23. --Changes of crab biomass (in t/km<sup>2</sup>) with time in Region 2 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

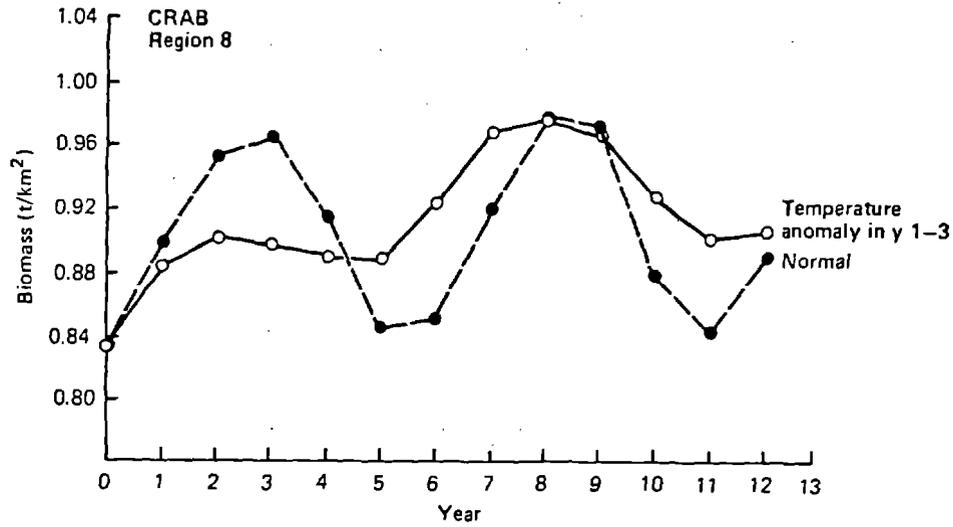


Figure 24. --Changes of crab biomass (in  $t/km^2$  with time in Region 8 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

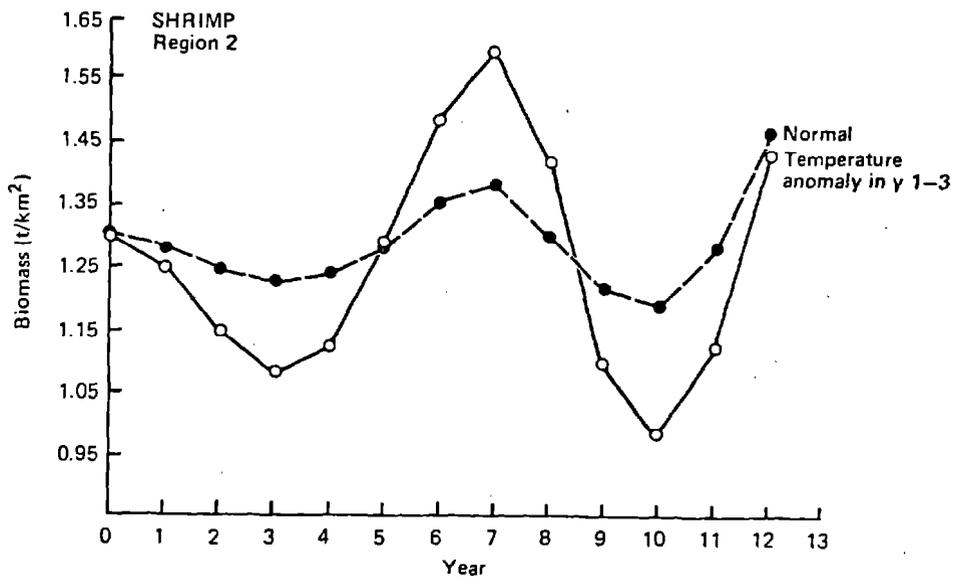


Figure 25. --Changes of shrimp biomass (in  $t/km^2$ ) with time in Region 2 in normal conditions and with temperature anomaly in years 1 to 3 (-1.5; -2.5; -1.5°C, respectively).

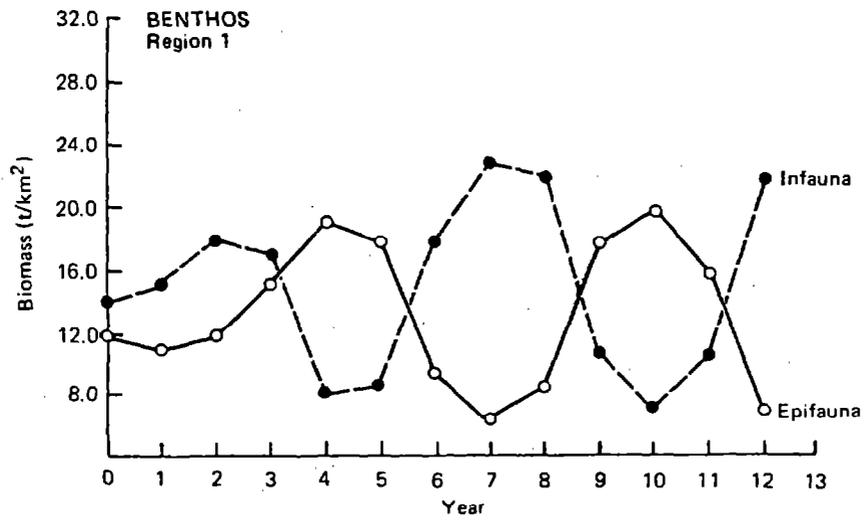


Figure 26. --Changes of the biomass of infauna and epifauna (in t/km<sup>2</sup>) in Region 1.

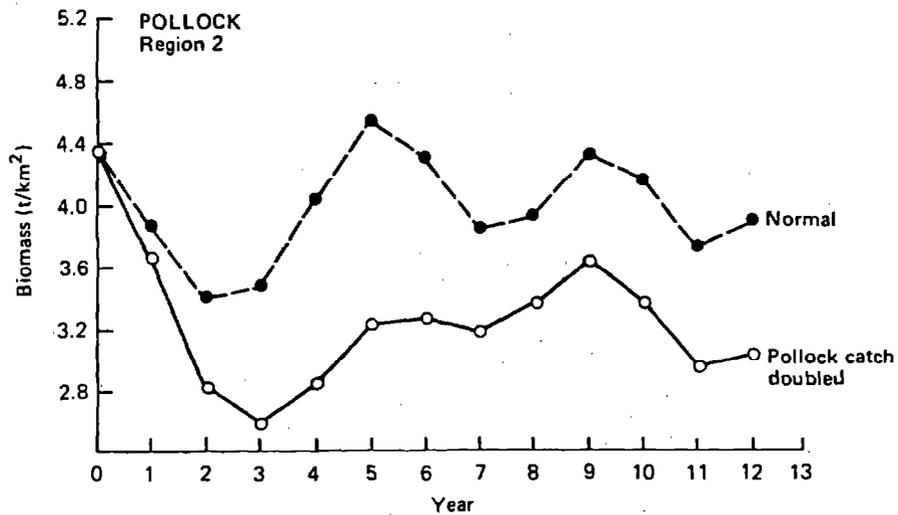


Figure 27.-- Changes of pollock biomass (in t/km<sup>2</sup>),with time in Region 2 in normal conditions and with doubled fishery (catches) of pollock.

### Effect of increasing the pollock catch

In another experiment the pollock catch was doubled in year one. In the “control” run, the pollock catch was 1.1 million tonnes from the eastern Bering Sea, .45 million tonnes from the Aleutian regions, and .32 million tonnes from the Gulf of Alaska. These values correspond approximately to present (1981) catches. It should, however, be pointed out that the present catch is small in relation to the total biomass of pollock present in the NE Pacific (ca 18 million tonnes in eastern Bering Sea and Aleutian region). Thus, the doubling of the catch would still hold it below any possible “over-fishing” criterion. The resulting changes of selected biomasses after the doubling of pollock catches are shown in Figures 27 to 33.

a) The doubling of pollock catch decreases the pollock biomass by less than 30% of its equilibrium value (Figures 27 to 29). The resulting new biomass is in equilibrium with the rest of the ecosystem within a few years.

b) The magnitudes of fluctuations of heavily fished pollock are somewhat dampened. This is considered a general phenomena; the lower the equilibrium biomass, the smaller the magnitudes of fluctuations.

c) The biomasses of most other species (e.g. cod, Figures 30 and 31; herring, Figure 32; and cottids, Figure 33) are slightly increased. This is mainly caused by decreased predation by older pollock on the other species.

### Effects of a reduction in marine mammal consumption

In a third experiment the consumption by marine mammals was reduced 30%. The effect of this reduction on the fish biomasses is variable from region to region, partly due to the distribution of mammals in space and time. The regional variation is shown with *two* examples in Table 3.

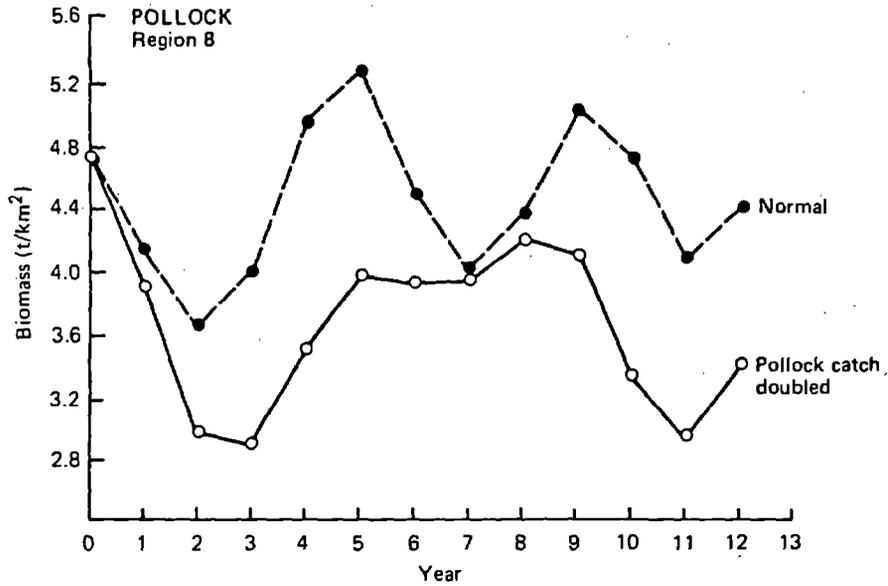


Figure 28. --Changes of pollock, biomass (in t/km<sup>2</sup>) with time in Region 8 in normal conditions and with doubled fishery (catches) of pollock.

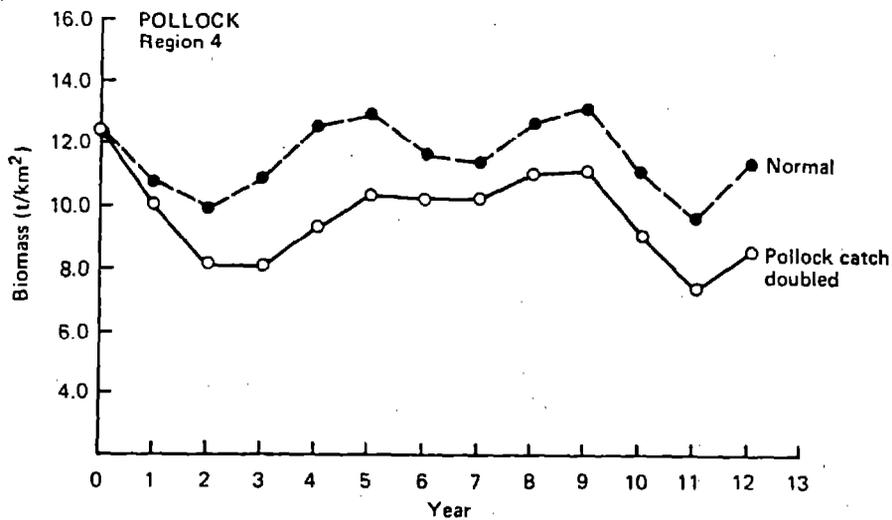


Figure 29.--Changes of pollock biomass (in t/km<sup>2</sup>) with time in Region 4 in normal conditions and with doubled fishery (catches) of pollock.

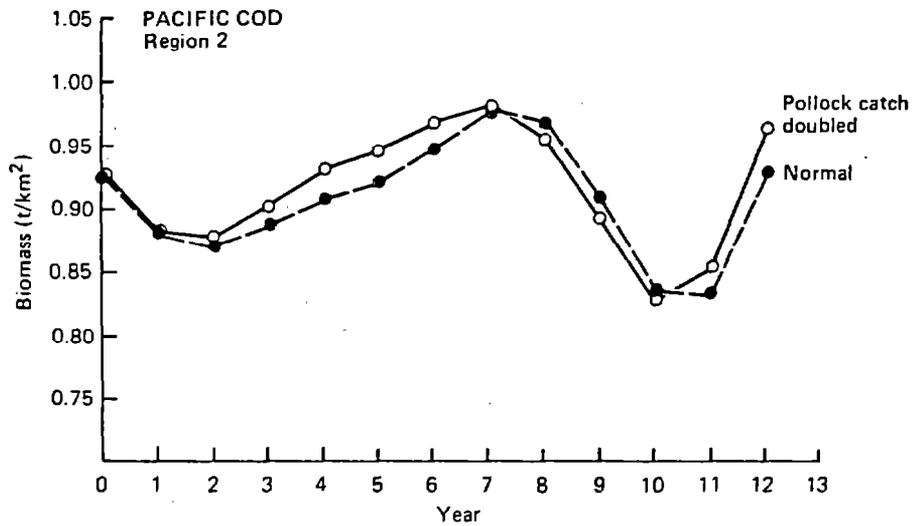


Figure 30.-- Changes of Pacific cod biomass (in t/km<sup>2</sup>) with time in Region 2 in normal conditions and with doubled fishery (catches) of pollock.

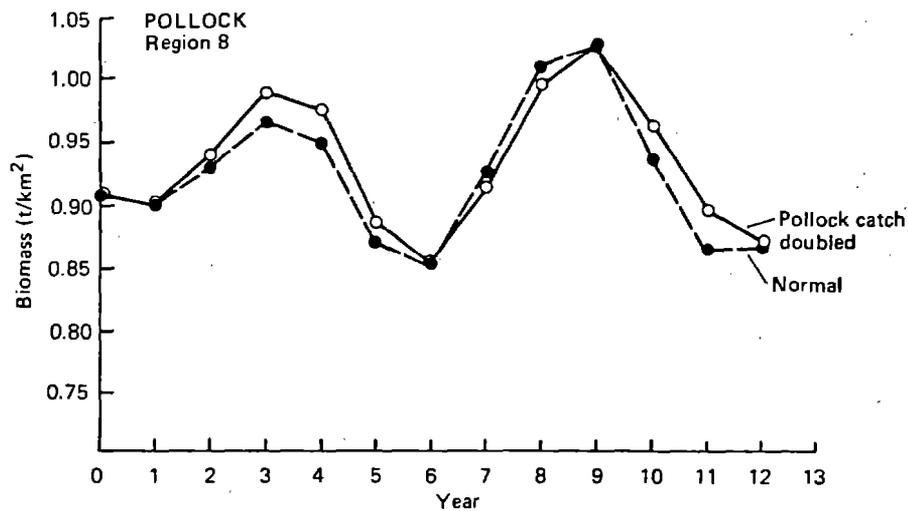


Figure 31. - -Changes of Pacific cod biomass (in t/km<sup>2</sup>) with time in Region 8 in normal conditions and with doubled fishery (catches) of pollock.

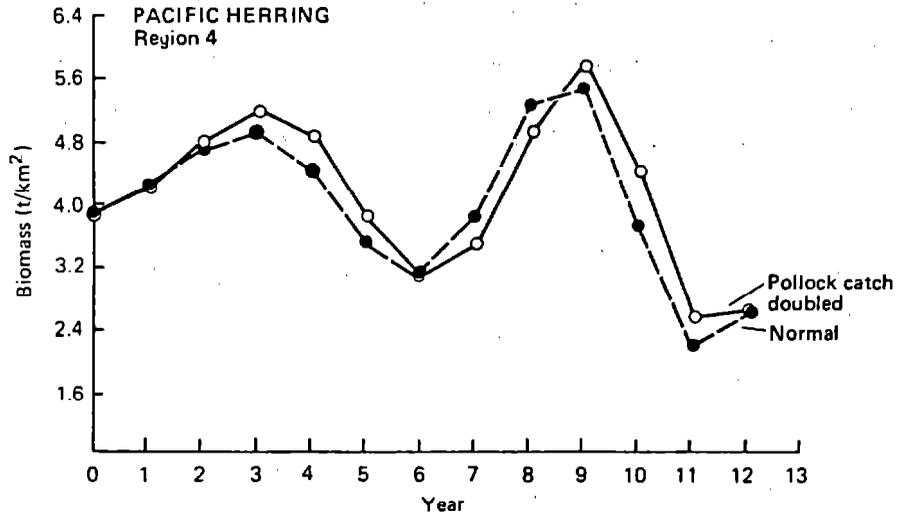


Figure 32. --Changes of Pacific herring biomass (in t/km<sup>2</sup>) with time in Region 4 in normal conditions and with doubled fishery (catches) of pollock.

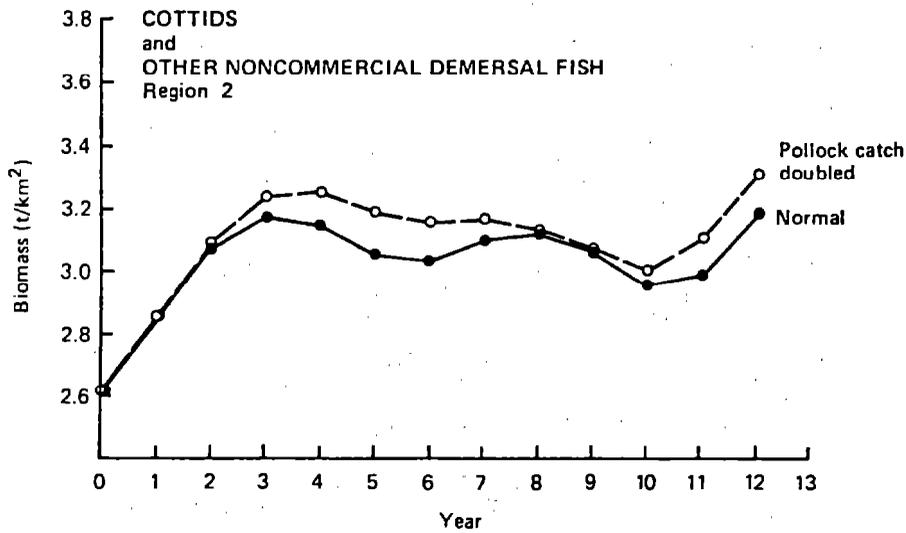


Figure 33.--Changes of cottids and other noncommercial fish biomass (in t/km<sup>2</sup>) with time in Region 2 in normal conditions and with doubled fishery (catches) of pollock.

Table 3.--Consumption by marine mammals (in 1000 tonnes) in Regions 2 and 8 with normal run and with reduced mammal consumption run.

Ecological group consumed	Region 2		Region 8	
	Normal run	Reduced consumption	Normal run	Reduced consumption
Demersal fish	124	95	32	25
Semidemersal fish	291	235	139	80
Pelagic fish	172	145	79	60
Squids	103	99	55	50
Benthos	683	518	50	48

The total consumption of finfish by mammals in the eastern Bering Sea has been estimated to be about 4 million tonnes. The 30% reduction of this consumption resulted only in modest increase of the biomasses of most species (Figures 34 to 37). The increase was in general less than 10% of equilibrium biomass. An exception is the squid biomass in oceanic regions (Region 5, Figure 37), where the biomass increase was larger because the squids are an important food resource for mammals in this region.

#### Fluctuations of total biomass

The natural fluctuations of biomasses of different species is dominated by fluctuations with a period of 4 to 8 years (Figures 14 to 37). Fluctuations with approximately this period are known in most stocks from the North Atlantic (e.g., Figure 9 after Garrod from Cushing 1981). The periods seem to vary slightly from species to species and are largely influenced by life history of the species. Superimposed on these fluctuations are other long-term fluctuations, lasting for decades, which are not investigated in this study.

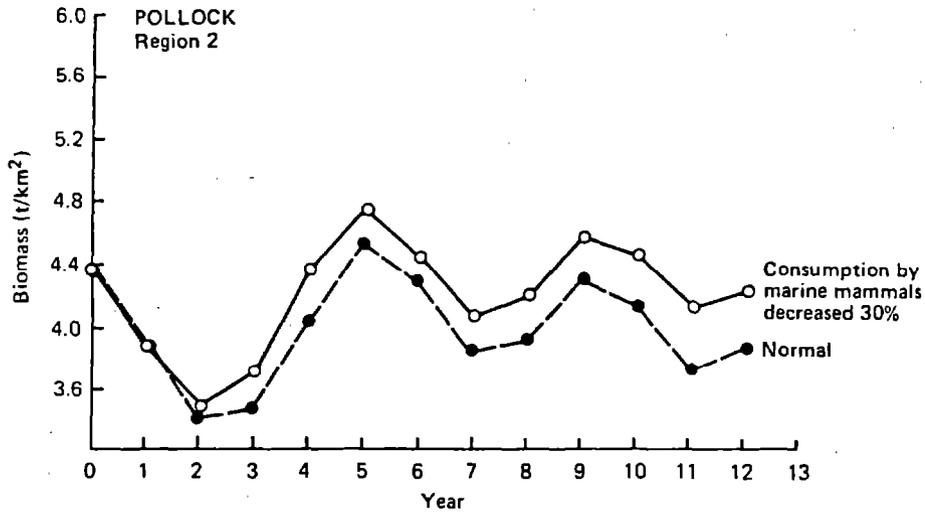


Figure 34. --Changes of pollock biomass (in t/km<sup>2</sup>) with time in Region 2 in normal conditions and with 30% reduction of consumption by marine mammals.

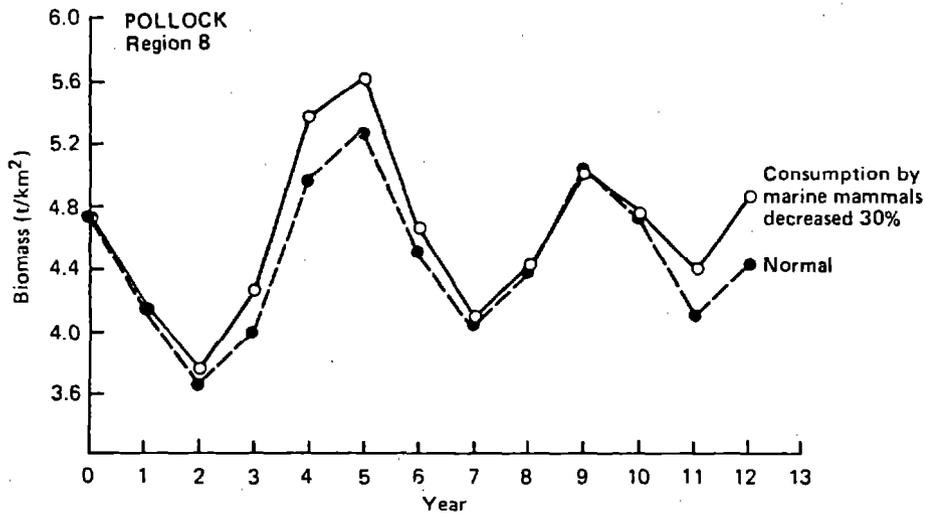


Figure 35. --Changes of pollock biomass (in t/km<sup>2</sup>) with time in Region 8. in normal conditions and with 30% reduction of consumption by marine mammals.

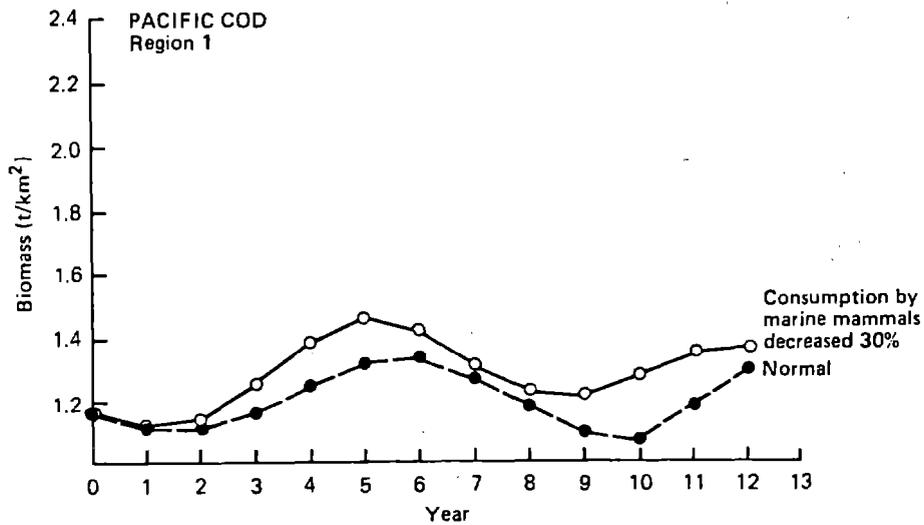


Figure 36. --Changes of Pacific cod biomass (in t/km<sup>2</sup>) with time in Region 1 in normal conditions and with 30% reduction of consumption by marine mammals.

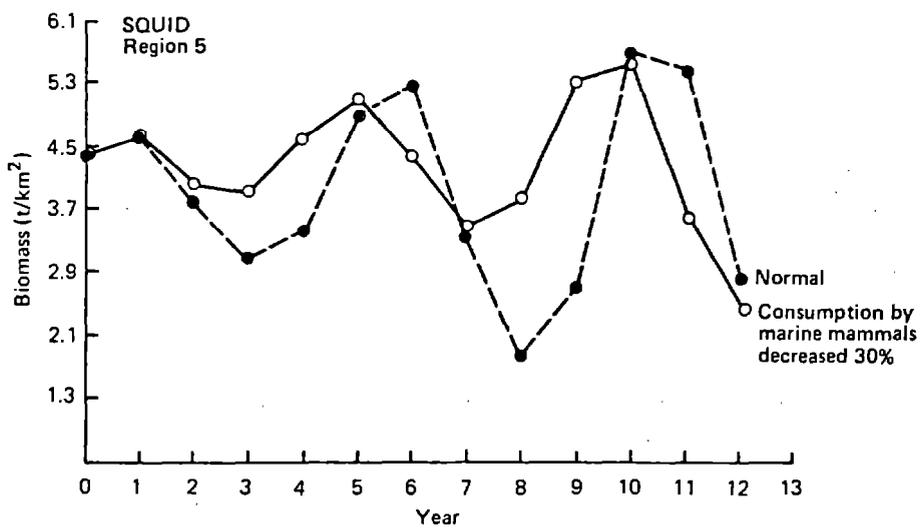


Figure 37.--Changes of squid biomass (in t/km<sup>2</sup>) with time in Region 5 in normal conditions and with 30% reduction of consumption by marine mammals.

The magnitudes of the natural fluctuations vary also from species to species and are influenced by various ecosystem internal as well as external factors. Furthermore, the fluctuations vary from one region to another.

The fluctuations of total finfish biomass in 4 regions over 11 years is shown in Figures 38 to 41. The total finfish biomass fluctuates less than 10% from the equilibrium biomasses in other regions than the offshore Region 3 in the Bering Sea. The maximum fluctuation in the latter region is 20%. The mean period of fluctuation of total fish biomass is ca 5 years.

Temperature anomaly affects the fluctuations of total fish biomass, because temperature affects the growth rate of all species. With the prescribed temperature anomalies the effect is about 7% lowering of biomass in the third year, except in offshore Region 3, where the lowering is ca 20%.

The doubling of pollock catch lowered the total biomass in most regions a few percent. This is mainly a consequence of the dominance of pollock biomass in the North Pacific, which is over 50% of the total finfish biomass in most regions. The lowering of consumption by marine mammals by 30% increased the total biomass in coastal regions (Figures 38 and 40) only a few percent, but the increase in offshore regions (Figures 39 and 41) was between 5 and 10%. The period of fluctuations was shortened one year (to 4 years).

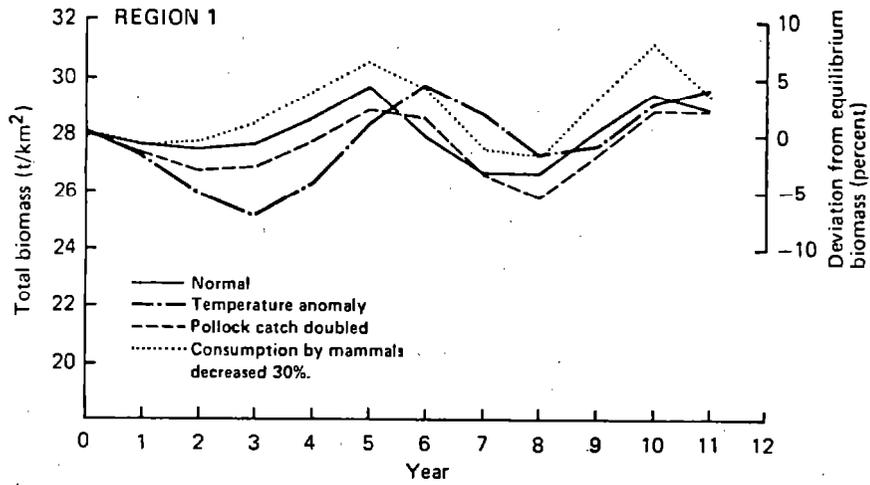


Figure 38. --Change of total finfish biomass with time in Region 1 (in t/km<sup>2</sup>) and deviation (in %) from total equilibrium biomass.

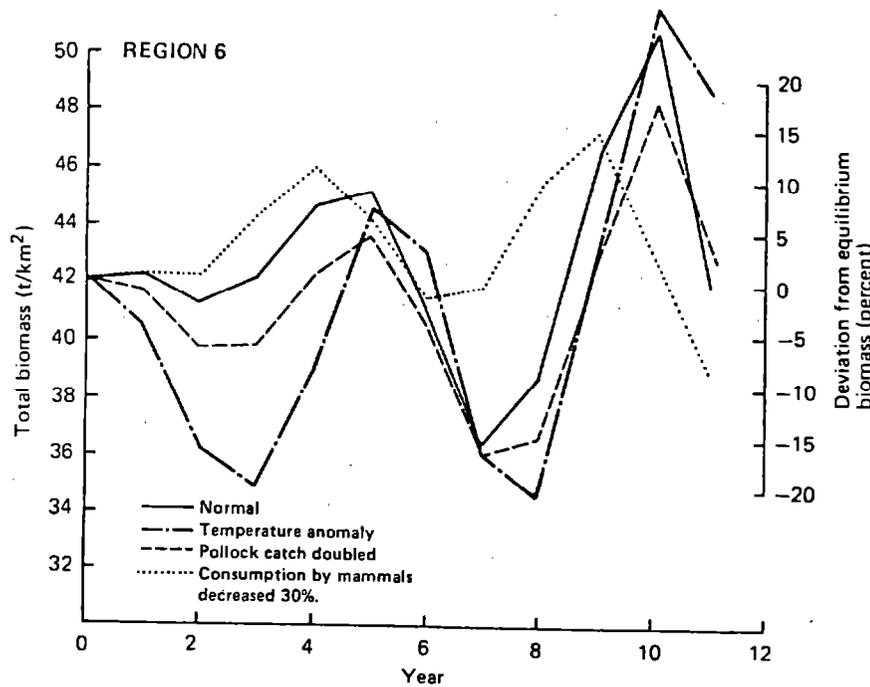


Figure 39.--Change of total finfish biomass with time in Region 3 (in t/km<sup>2</sup>) and deviation (in %) from total equilibrium biomass.

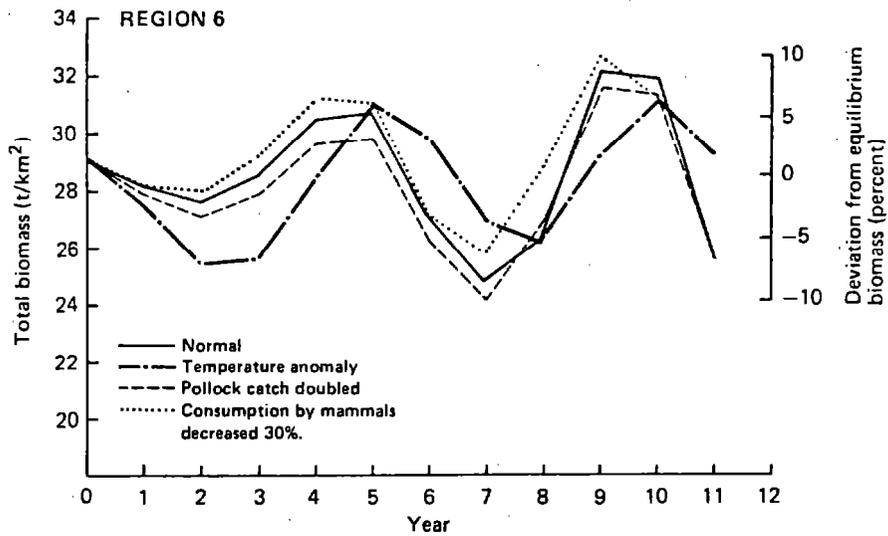


Figure 40. --Change of total finfish biomass with time in Region 6 (in t/km<sup>2</sup>) and deviation (in %) from total equilibrium biomass.

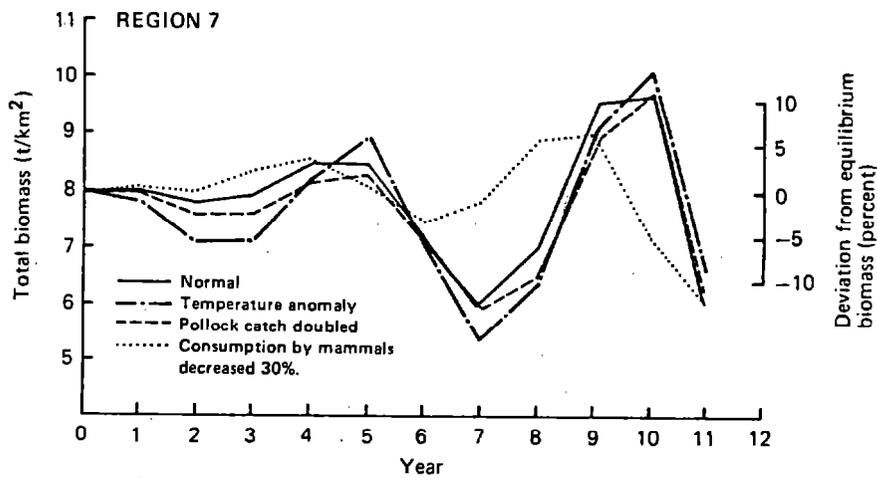


Figure 41.--Change of total finfish biomass with time in Region 7 (in t/km<sup>2</sup>) and deviation (in %) from total equilibrium biomass.

## 5. RATES OF CHANGES OF BIOMASSES AND “STOCK RECOVERY” RATES

A fluctuating biomass implies change of biomass with time. The rates of changes vary from species to species, and are dependent on a number of factors such as the intensity of the forcing agent and the state of the biomass itself (i.e. density dependence of change). The incline rate of the stock is usually termed “stock recovery” rate, and the knowledge of it is applied in fisheries management.

The annual rate of biomass changes of any species is affected by a number of factors:

a) Predation (mortality), which operates mainly on larvae and juveniles, and is dependent on various predator-prey relations, (i.e. the density of both in space and time or the “predator-prey overlap”), suitability (vulnerability) , etc.

b) Fishing mortality which operates on adult portion of biomass. (When fishing mortality increases, spawning stress mortality decreases. Biomass growth rate increases also with increasing fishing mortality (“rejuvenation of population”.)

c) Spawning stress mortality, which is dependent on age of maturity and age frequency composition of mature biomasses. It follow Gampertz’ law and is predictable.

d) Natural mortality (from diseases and starvation), which is usually small provided no “plagues” prevail.

e) Recruitment, both larval recruitment (“spawning success”) and recruitment to adult population. The former is affected by fecundity, spawning biomass present, and environmental anomalies; the latter is mostly controlled by predation.

f) Growth rate of biomass, which is dependent both on individual growth rates and age structure of the population, and is affected by environmental temperature anomalies and food availability.

g) Immigration and emigration.

All the above listed biomass change-affecting factors are accounted for in the PROBUB runs for this study, except immigration and emigration which were assumed to be zero. The effects of migrations on biomass changes can be studied separately with DYNUMES model which allows for better accounting for predator-prey overlap effects than PROBUB does. The biomass change might be affected simultaneously by several of the factors with different frequencies of occurrence, thus causing irregular fluctuations of biomass as observed in empirical data (see Chapter 2). Therefore, the relatively regular variations computed with the PROBUB model (Figures 14 to 37) can give only a quantitative insight into the magnitudes of the fluctuations and of the periodicities inherent in the system. However, real-time fluctuations can also be simulated if the magnitudes of anomalies and times of occurrences are known or can be predicted.

The annual rates of change of biomasses were computed as  $\frac{B_1 - B_2}{B_e}$  and expressed in percent, where  $B_1$  and  $B_2$  are the biomasses in consecutive years and  $B_e$  is equilibrium biomass of the species. The resulting data on change rates and mean periods and magnitudes of fluctuations are summarized in Table 4. Some additional observations of the rate of change of biomasses can be made from Figures 14 to 37:

Table 4.--Some typical annual rates of changes of biomasses (with reference to equilibrium biomasses) and typical periods and magnitudes of fluctuations of biomass. ( $B_1 - B_2$ )

Species/ecological group	Annual change in percent of equilibrium biomass		Fluctuations	
	Range	Mean	Mean period, years	Mean magnitude (+%)
Flatfishes	7.5 to 13	10.5	6 to 7	45
Sculpins and other noncommercial demersal	8 to 26	12	5	40
Cod	7 to 20	13	7	35
Pollock	11 to 34	19	5	75
Herring	20 to 50	38	5	80
Squids	35 to 70	50	4	100
Benthos	65 to 80	75	4	120

a) The rates of change of biomasses are dependent on the type of the species (e.g. flatfishes, semidemersal fishes, etc.). Further, the magnitudes and periods of fluctuations are influenced by life length and rate of growth of the species.

b) Rates of decline tend to be more rapid than rates of incline.

c) The computed mean periods of fluctuations (4 to 7 years) correspond roughly to the periods observed in empirical data (see Chapter 2). Obviously the observed “periods” are more irregular due to irregularities in occurrence of factors causing them, as discussed above.

The mean values of the annual rates of change in Table 4 might be considered as mean “stock recovery rates”. However, we need to be aware of four other conditions in their application for estimating stock recoveries;

1) The rate of change' in Table 4 applies to whole biomass and not to exploitable portion only. There might be a time lag involved in "buildup" of exploitable part (on the order of 1 to 3 years).

2) The recovery might be interrupted by pronounced environmental anomalies.

3) When the recovery rate is applied, the spawning biomass should not be at a very low level, so that larval recruitment is seriously affected. In the latter case the recovery is relatively slow, unless exceptional larval survival occurs in a few years.

4) A given low stock level might be a consequence of long-term fluctuations and "species replacement" (not dealt with in this paper, but see Daan 1980), in which case recovery might be slow because of condition 3 above and because of increased competition with "replacing" species.

Predation is one of the main ecosystem internal factors "guiding" the quasi-periodic fluctuations (see Figure 11). Therefore, it is of interest to know the magnitudes and variations of predation, which are given in summary form in Table 5 as average monthly consumption. This consumption rate is mainly dependent on the growth rate of the species. Table 5 also gives annual turnover rates of the biomasses. Individual turnover rates vary with life length and growth rates of the species. The turnover rates also vary somewhat from region to region and from year to year.

Table 5.--Normal ranges of turnover rates and percent of monthly consumption of biomass.

<u>Species/ecological group</u>	<u>Turnover rates</u>	<u>Monthly consumption (% of biomass)</u>
Flatfishes	.35 to .70	3.0 to 6.0
Semipelagic fishes (gadids)	.65 to .80	5.0 to 6.5
Pelagic fishes	1.0 to 1.1	8.2 to 8.8
Squids	1.7 to 2.0	6.5 to 11.8
Shrimps	.70 to .95	5.5 to 7.5
Crabs	.50 to .65	4.2 to 5.2
Benthos	1.2 to 1.7	10.5 to 14.5

## 6. IMPLICATIONS OF THE FLUCTUATIONS OF STOCK TO FISHERY

The basic interest of fishermen is in obtaining the highest possible monetary return from their fishing activities. The fluctuating stocks (abundance) impinges on the fishermen's earnings in three different ways:

First, a fluctuating stock means fluctuating availability of the species to fishery, thus a variable return on effort. (Availability and variability in fishability might also be caused by weather and changing migrations of the species.) In addition, the fishing intensity (effort) on many if not most, species responds to market conditions. Thus, a fluctuating stock (availability) would influence earnings in fisheries as well as availability to markets and market prices.

Second, many fisheries are specialized to fish one or a few species (stocks), using specially adapted gear and vessels. Fluctuating stocks would affect these specialized fisheries, causing fluctuations in catch and even requiring a switch to other target species when preferred species availability is low. Thus, fluctuating stocks require flexibility in fisheries in respect to selection of target species. On the other hand, switching of fishery to another target species can also cause changes in the ecosystem (i .e., in relative abundance of the species).

Third, a fluctuating stock will require more search time as well as fishing effort when the stock is at the low level of the fluctuating cycle. This would result in increased costs and diminished returns. A stock at a high level of abundance would cause either an increase in profits or a fall in prices if the market is saturated. Thus, a fluctuating stock would require flexibility in marketing, in preparing the product, or replacing less available species with more abundant species in the markets. It is in

general recognized that the fishing business is an uncertain one, mainly due to fluctuations and other rises, and consequently the investment of capital to fishing industry is hampered.

There are three consequences of fluctuating stocks to fishery, which have been often overlooked and thus need to be emphasized.

1) The economic value of the components of the fish ecosystem varies with the availability (abundance) of the commercially desirable species. It seems to be desirable to introduce to discriminating markets those species which could replace, at least partially, the desirable species when their availability is low.

2) Modern, large-scale fishery must be flexible, i.e., able to switch from one target species to another when availability of selected target species changes. Thus, very special vessels and gear are not profitable investments over long periods. (This shortcoming is at present apparent in the Bering Sea crab fishery where only a few vessels could be converted with reasonable costs to fish, e.g., cod, when the crab resource decreased rapidly in recent years. )

3) The fish processing and marketing industry must also be flexible and not high specialized, but prepared for changes according to availability of species. These possible changes should be communicated in a timely manner to the fishing industry, which needs to be informed of the quantitative composition of the marine fish ecosystem and changes occurring within it.

## 7. RATIONAL FISHERIES MANAGEMENT OF FLUCTUATING STOCKS

The Magnuson Fishery Conservation and Management Act of 1976 established eight regional councils to manage fishery resources in the U.S. fishery conservation zone. The Act requires that the councils develop fishery management plans for major fisheries that fall under their jurisdiction. One requirement of a plan is the specification of allowable catches for relevant species or groups of species. Since a fishery based on one species could affect the biomasses of others, it is important to know the nature of the relationships that exist between species. Further; it is important to know how fluctuations in nontarget species will affect those 'targeted upon. Failure to give adequate attention to these considerations could result in adoption of management measures that could adversely affect the fishing industry and prevent achievement of management goals specified for the fishery.

Rational fisheries management requires detailed knowledge of:

- a) the magnitude of the resource at any given time;
- b) natural fluctuations of the resource and their causes;
- c) amount which can be taken any given year without unduly diminishing the productivity of the resource (i.e., the response of the resource to fishery) ;
- d) other peculiarities of the resource (e.g., its reproductive and growth capabilities, its migrations, and other availability affecting factors), which are pertinent for obtaining highest possible production and yield; and
- e) economic and social forces that influence the operation of a fishery and how they are affected by stock fluctuations.

In the past most fisheries have been managed on the basis of Maximum Sustainable Yield (MSY). It has been demonstrated that MSY does not exist (e.g., Larkin 1979). The fluctuations of the stocks also preclude the existence of a constant long-term sustainable yield. If MSY or a long-term allowable catch is set when stock abundance is low, resources would be wasted if the allowable catch is not increased when abundance increases. If the allowable catch is set when abundance level is high, overfishing could result and stock recovery might be inhibited if allowable catches remain fixed. Thus, in the case of fluctuating stocks the fishery must be managed on an annual basis.

Management of fluctuating stock on an annual basis requires an accurate evaluation of the resource and the state of its fluctuation. The effect of present and predictable future environmental anomalies on the stocks must also be accounted for in the assessment. Furthermore, the response of the stock to present or proposed fishery must be determined in an ecosystem context where species interactions and stock fluctuations are taken into account.

Management of fisheries on an annual basis requires that:

First, the managers must be aware that fishery on one species also affects the biomasses of other species, requiring a holistic ecosystem approach for the evaluation of the consequences of management options.

Second, options must be provided to fishery to switch the emphasis from one target species to another if fluctuating availability so requires.

Third, heavy fishing on dominant species in the ecosystem suppresses the fluctuations of this species, but not necessarily the fluctuations in other

species which are affected by fishery through-interspecies interactions (predation).

Fourth fishery cannot be stopped (prevented) on any species--there will always be bycatches and one can seldom minimize bycatch. Bycatch is discarded in many fisheries; however, discards should be utilized by man as very few, if any, of them survive.

The following procedure represents one method that could be used to estimate the annual allowable catch in fluctuating stock:

- 1) Determine the sign of change (+ or -) of the biomass in the last year (or in the last few years) and estimate near-future trend of the biomass changes, also considering possible environmental anomalies.
- 2) Determine the state of the stock in past (or present) year in relation to its equilibrium biomass using ecosystem simulation, and determine the allowable catch using the same ecosystem model.
- 3) Adjust the estimated allowable catch under following considerations:
  - a) if the biomass is declining, but is near the apex, allowable catch as determined on the basis of equilibrium biomass could be continued;
  - b) if the decline of biomass is in second or third year, the allowable catch (with reference to equilibrium biomass) should be lowered to correspond to biomass at the lower level of fluctuation;
  - c) if biomass is at low level of fluctuation, low allowable catch should be applied for two years;
  - d) if biomass has been increasing in past two years, heavy fishing (above the allowable catch for equilibrium biomass) for next two years is possible.
- 4) If the target species is a pelagic forage species, its biomass will respond, besides fishing, also to the predator biomasses. Thus, the state of predator biomasses must be considered in determining allowable catches:

a) if predator biomass is high, allowable catches should be lowered; b) if predator biomasses are low, higher fishing could be allowable. Pelagic and semipelagic species 'respond also to environmental anomalies, which must be accounted for in setting of allowable catch. --

5) It can happen in some species, especailly in longer-lived ones, that the total biomass- can be close to or below equilibrium biomass; but adult biomass is high, either due to little fishery or several consecutive good year classes. In this case, increased fishing effort can be applied with the knowledge that the catch per unit effort will decrease in a few years but that this decrease does not mean that this stock is overfished.

There are many other species and region-specific considerations applicable to the management of fluctuating stocks. These specific considerations will usually be apparent from the local, specific ecosystem simulation. The consideration of management options arising from socio-economic factors is outside the scope of this study.

## 8. SUMMARY

1) Marine fisheries ecosystem is unstable in the sense that the biomasses of individual species fluctuate considerably in time and space, although the total, fish biomass remains relatively constant, being only little affected by pronounced environmental anomalies.

2) The fluctuations of biomasses can occur without fishery, and are caused by temperature anomalies and by inter- and intraspecies interactions, such as predation and cannibalism. However, fishing affects these fluctuations.

3) The fluctuations of stocks are quite irregular. However, a general periodicity of 3 to 8 years is apparent in most data, indicating that there are some quasi-cyclic phenomena inherent in the ecosystem, such as life length of the species and recruitment cycles caused by strong year classes.

4) Although the numerical strength of individual year classes can vary three orders of magnitude, the biomasses are buffered by the presence of several year classes and do not fluctuate more than about one order of magnitude.

5) The fluctuations of biomasses are stabilized (limited) by density dependent predation (in reference to both predatory and prey density).

6) The temperature anomalies affect the fluctuations of biomasses more in northern regions than in southern regions. The anomaly effects are

7) The temperature anomalies can affect the predominantly forage species in opposite direction of the direct temperature effects by changing the conditions of predation by changing the biomasses of predators (predator and prey biomass relations in fish are about 1:3).

8) Changes in fishing pressure affect the biomass fluctuations 'in various ways. Heavy fishing lowers the adult biomasses and depresses the magnitudes of fluctuations.

9) Reduction of consumption (predation) by marine mammals influences the biomass levels of the principal prey species but has little effect on the periods and magnitudes of their fluctuations.

10) The annual rate of change of biomass is affected by a number of factors, such as spawning stress mortality, predation, fishing mortality; recruitment variations, and changes in growth rate of biomass.

11) The mean annual rate of change of biomass varies from one ecological group to another, being lowest in flatfishes (10% annually), followed by semidemersal species (13 to 20%), and pelagic fish (38%).

12) The mean period of fluctuations in finfishes varies from 4 to 7 years and the mean magnitude varies from 35% to 80% of equilibrium biomass.

13) The rates of decline of biomasses tend to be more rapid than rates-of incline.

14) The turnover rates of finfish biomasses vary from .35 to about 1.1.

15) Fluctuating stocks cause changes in fishery and require flexibility in switching from one target species to another.

16) As the main objective of fisheries management is to obtain maximum yield from the stock, the fluctuating stocks must be managed on an annual basis to achieve this goal.

17) Management of fluctuating stocks can be effected only on the basis of ecosystem simulations, as changes on one stock induce changes in other stocks.

18) A biomass near apex of its fluctuation can be fished more intensively than allowable catch computed from equilibrium biomass. An increasing biomass, although below equilibrium biomass-, can also be more heavily fished after the second year of increase.

19) The allowable catch in pelagic forage species is dependent on the state of predator biomasses present, which must be considered in management options.

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